Eric Y. Hsiao
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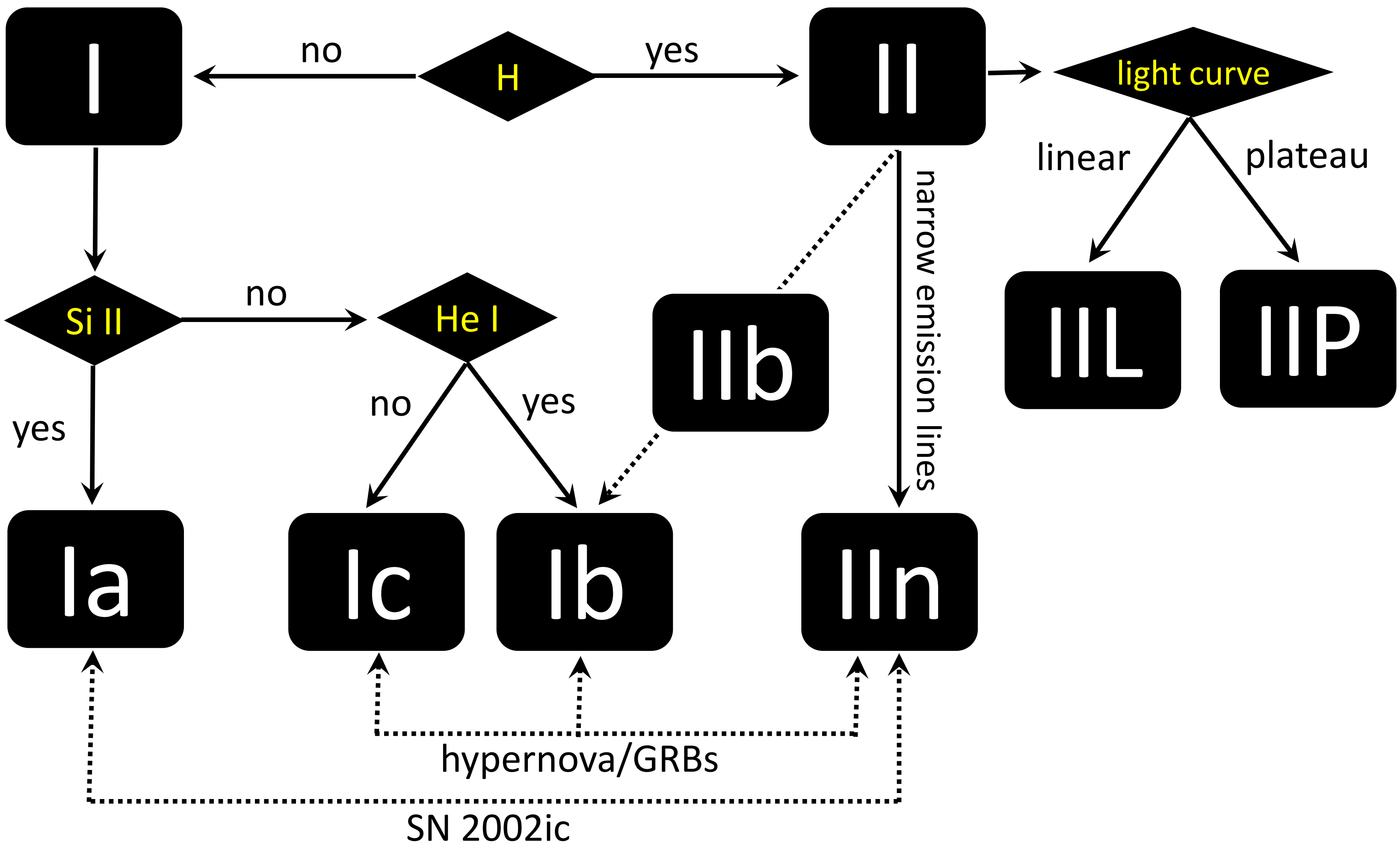
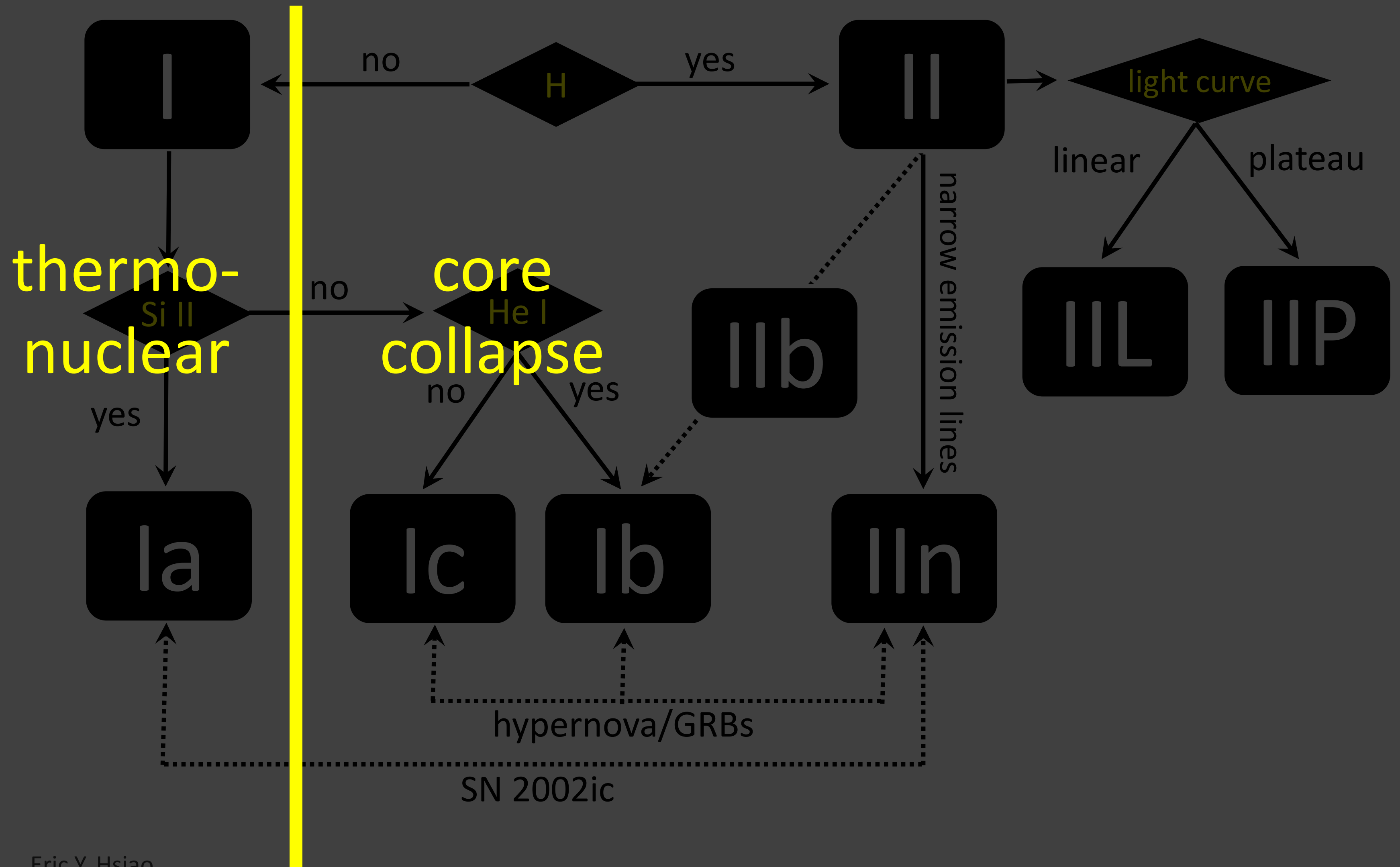
Spectroscopic diversity of Type Ia supernovae

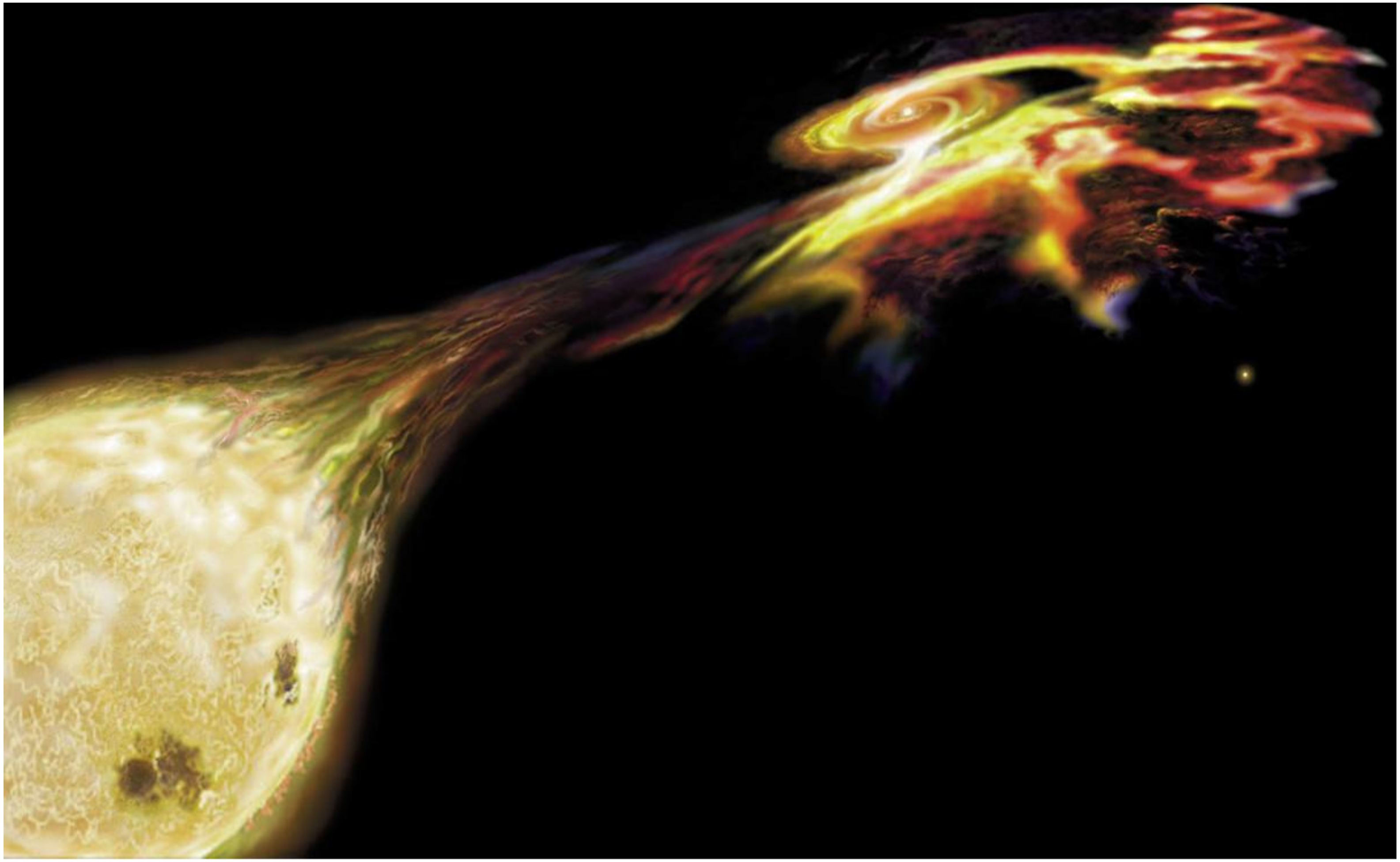
supernova classification



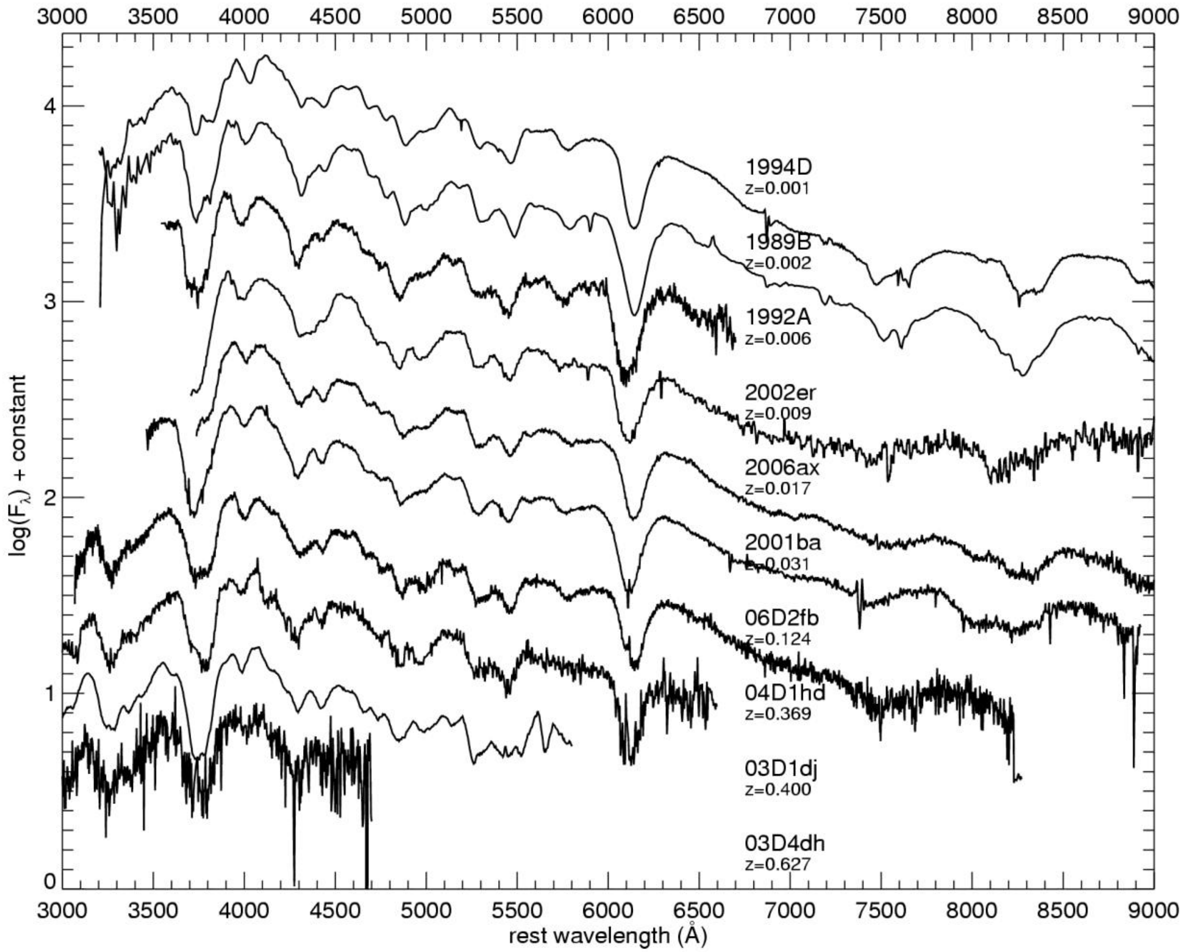
supernova classification



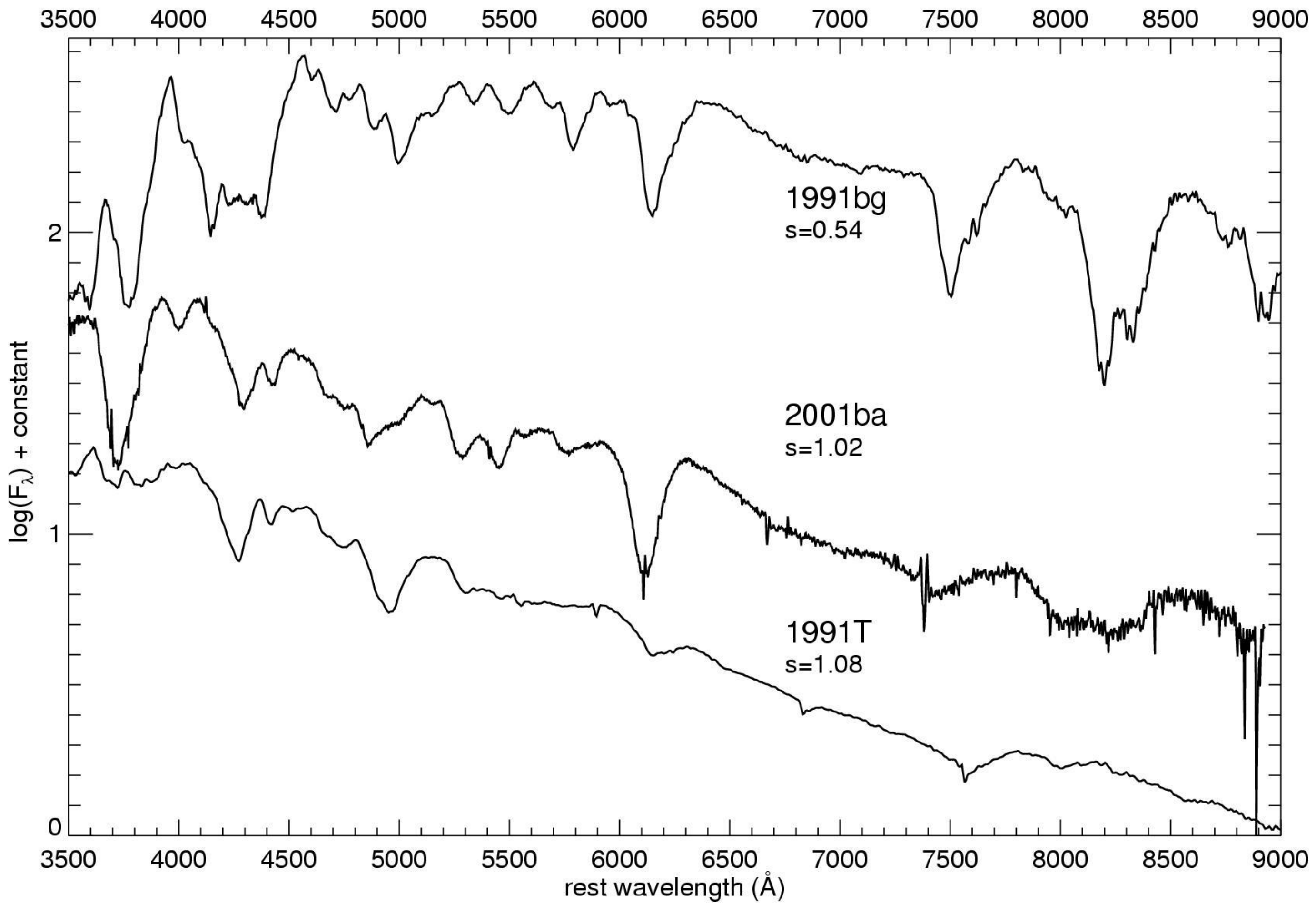
thermonuclear supernova



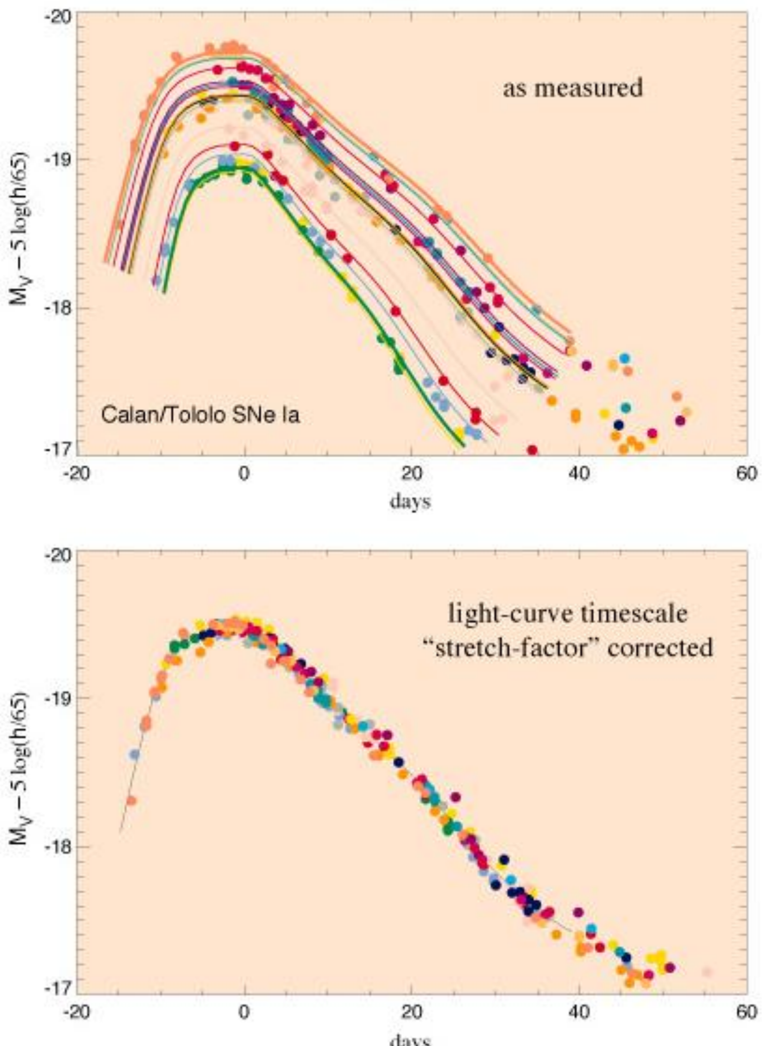
branch-normal SNe Ia



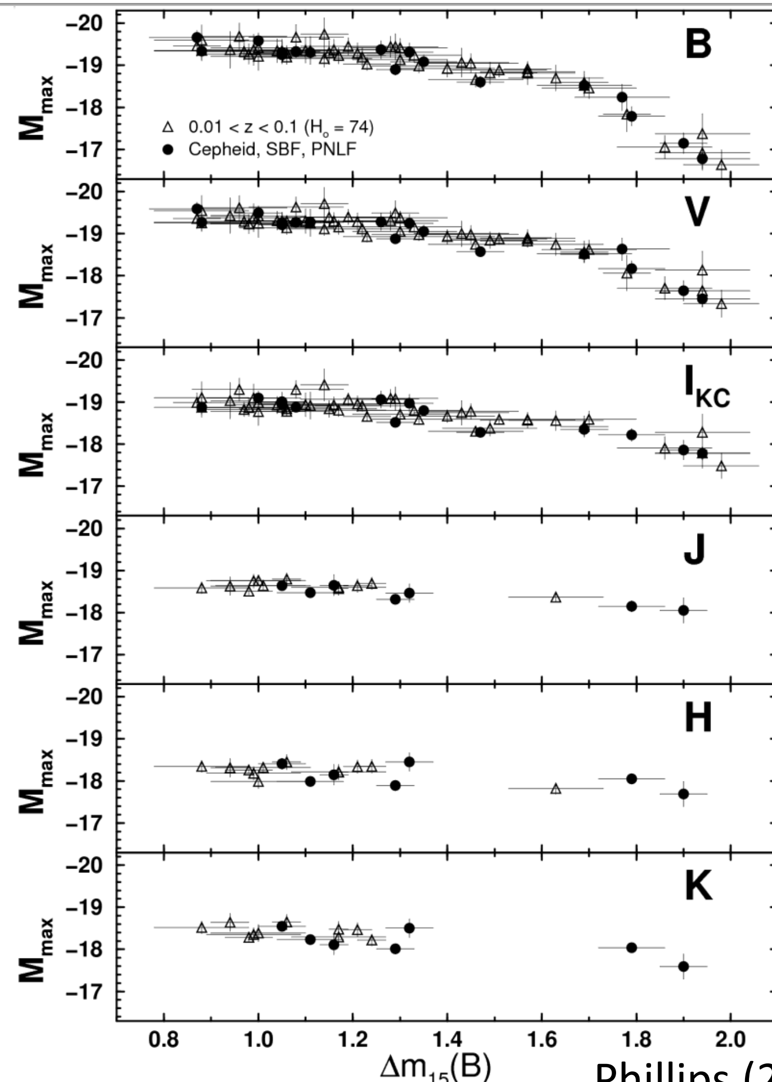
spectroscopically peculiar SNe Ia



width luminosity relation

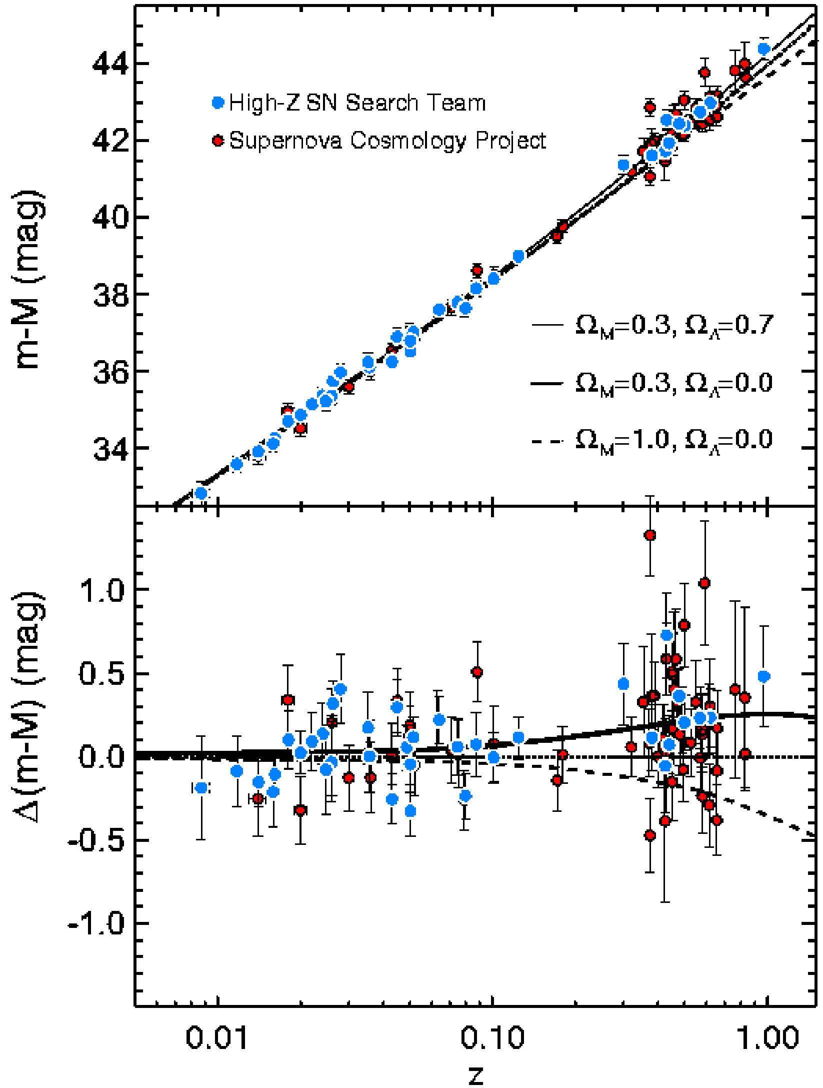


Perlmutter et al. (1997)



Phillips (2005)

discovery of dark energy

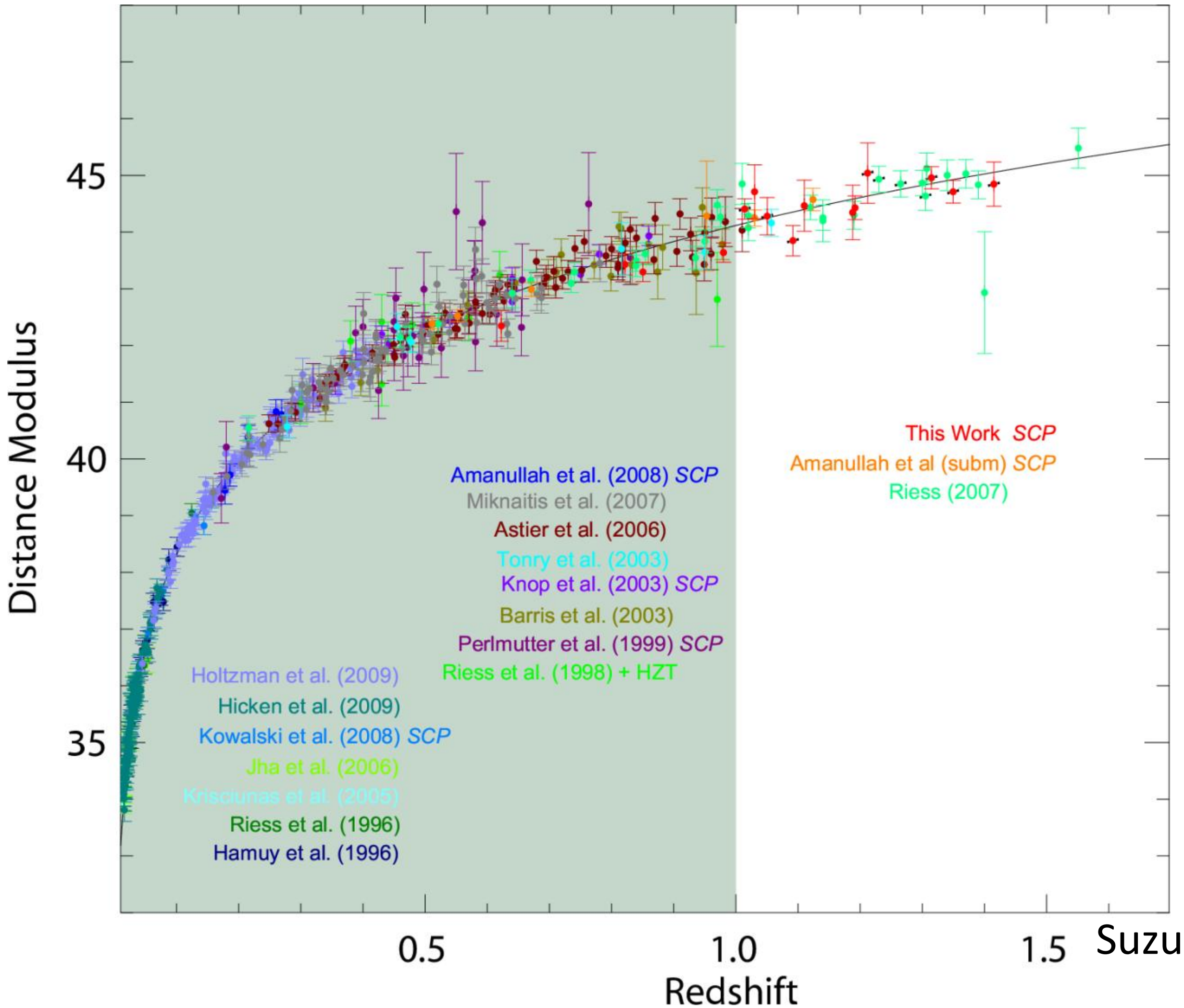


Riess et al. (1998)
Perlmutter et al. (1999)

SNe Ia surveys

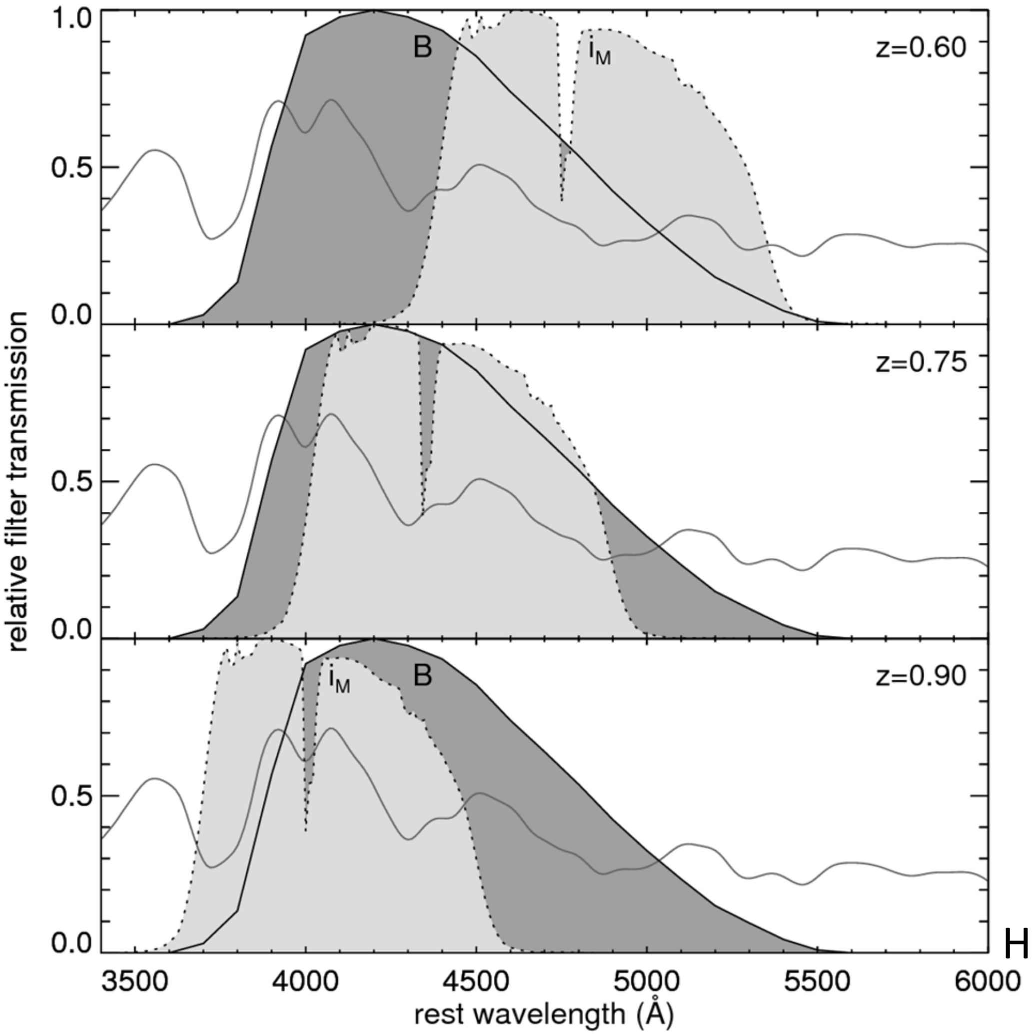
- SNLS – Supernova Legacy Survey
  - multi-band data for hundreds of SNe Ia $0.2 < z < 1$
- CSP – Carnegie Supernova Project
  - rest-frame I band Hubble diagram
- SCP – Supernova Cosmology Project
  - $z > 1$ SNe Ia by targeting clusters with HST
- SNF – Supernova Factory
  - spectrophotometric time series of nearby SNe Ia
- PTF – Palomar Transient Factory
  - optical transients from searches of various cadences

current optical hubble diagram



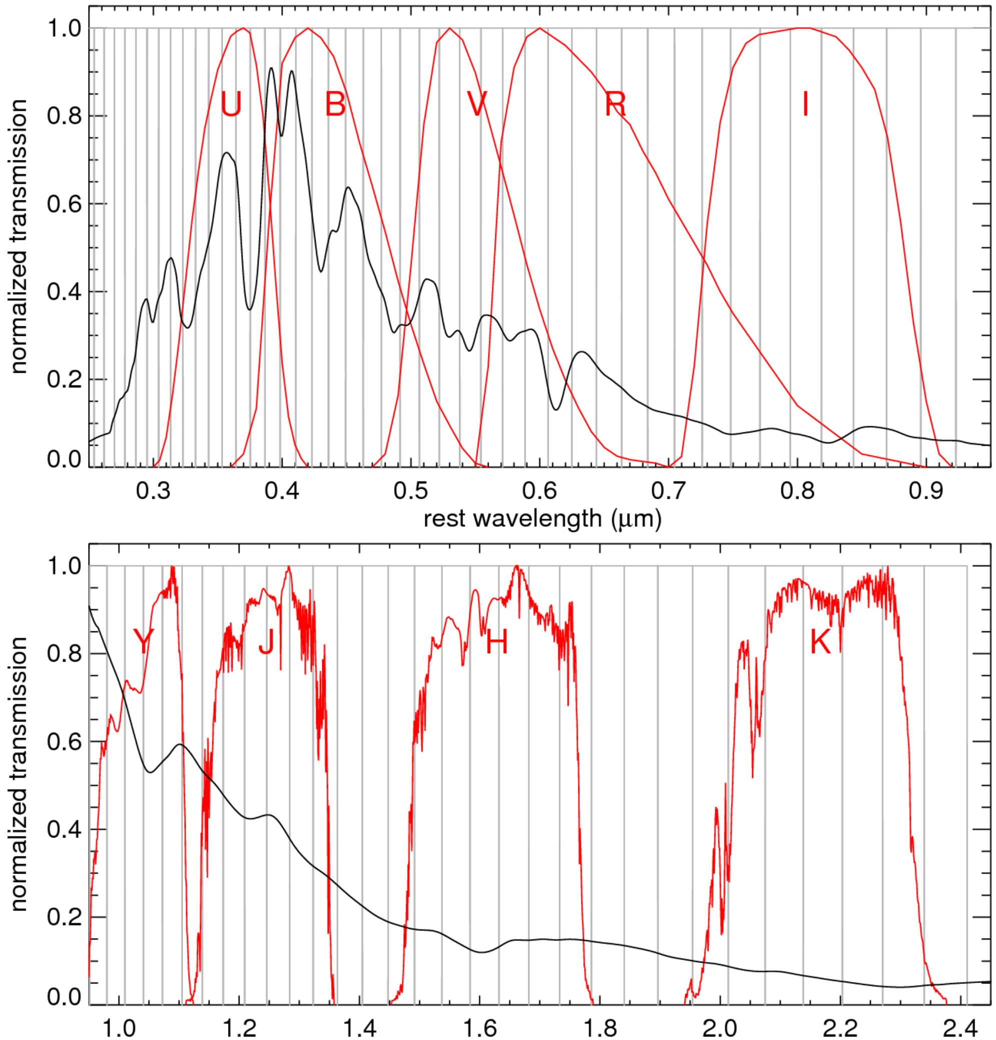
Suzuki et al. (2010)

K-corrections



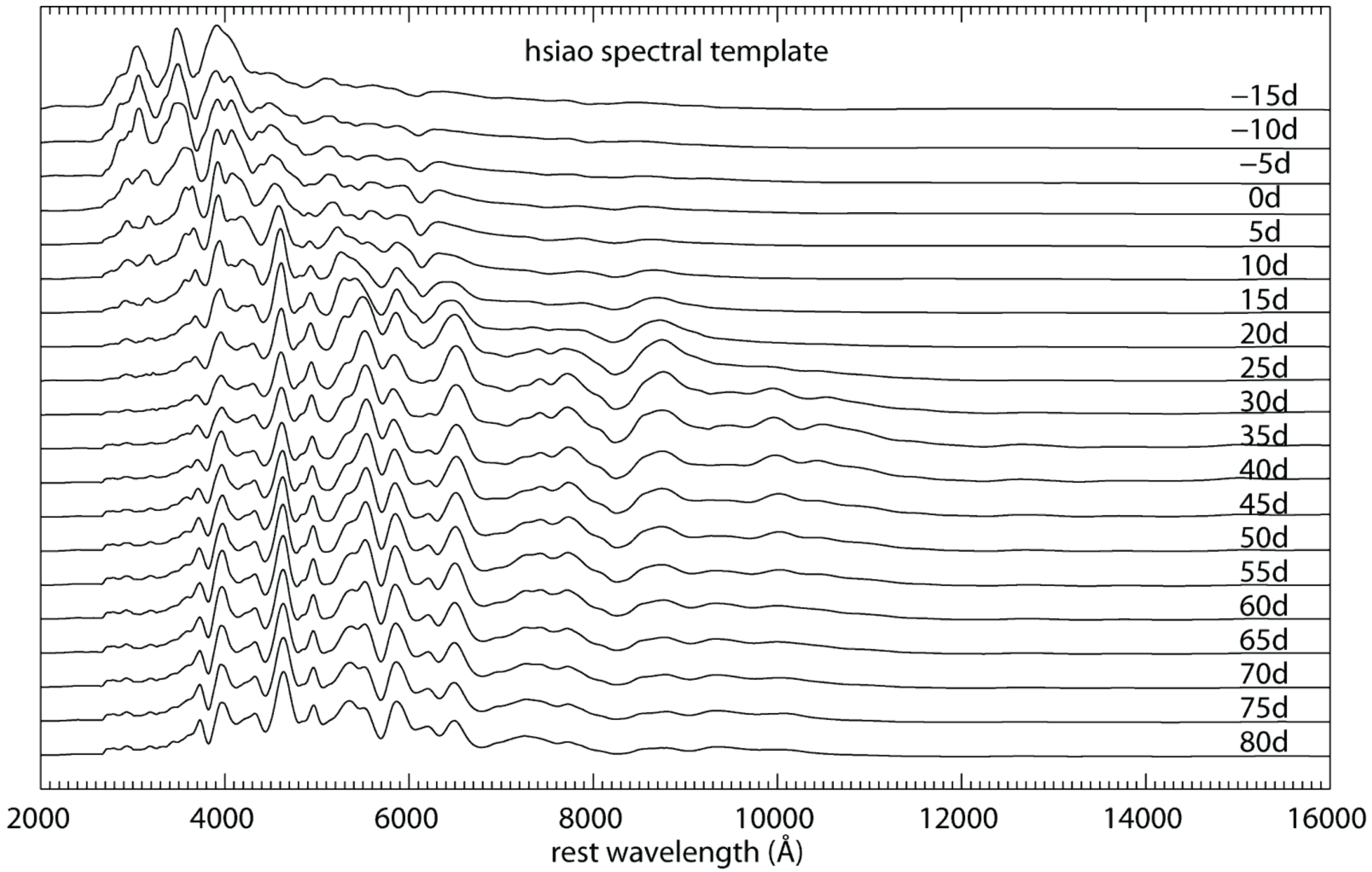
Hsiao et al. (2007)

consistent flux measurement

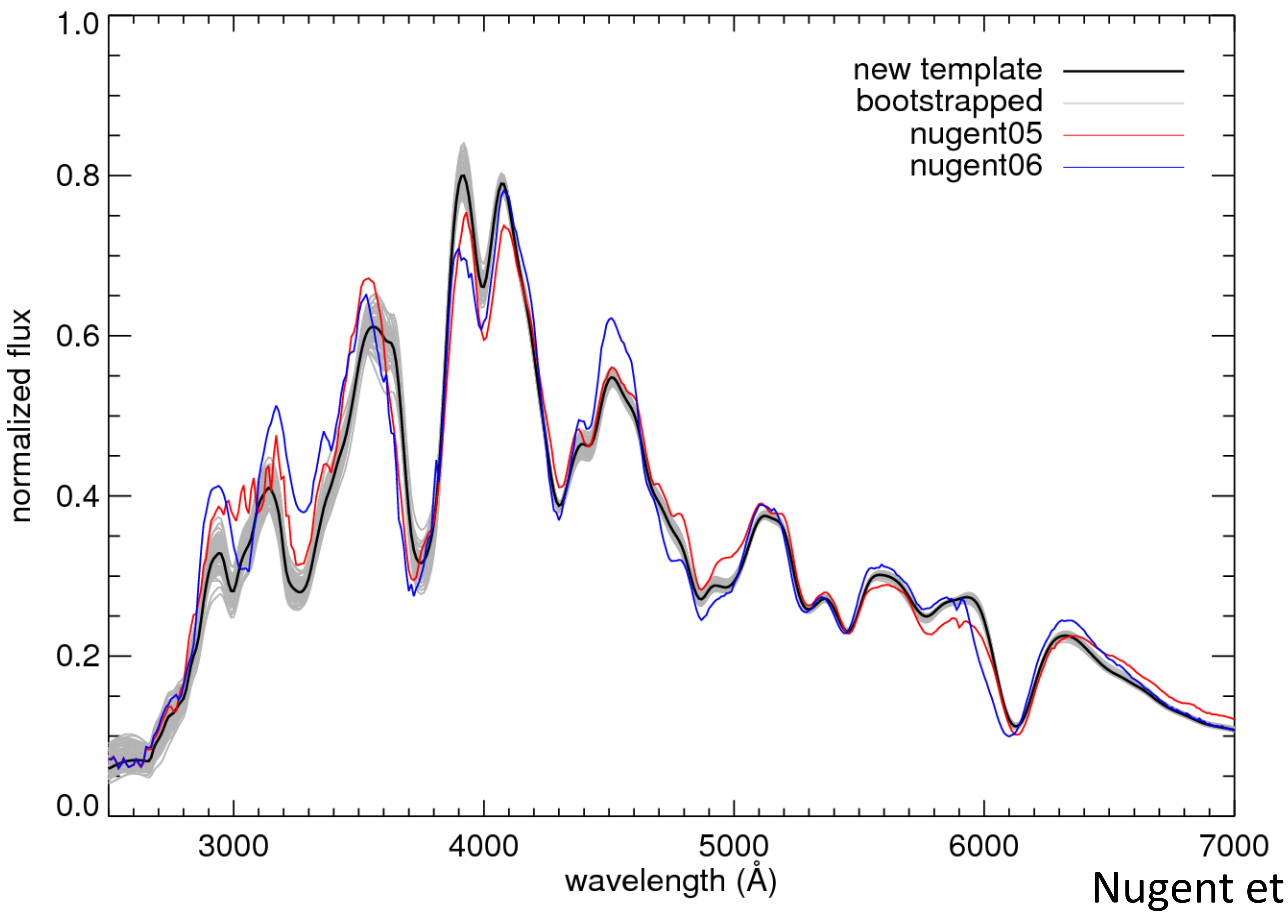


Hsiao et al. (2007)

hsiao spectral template

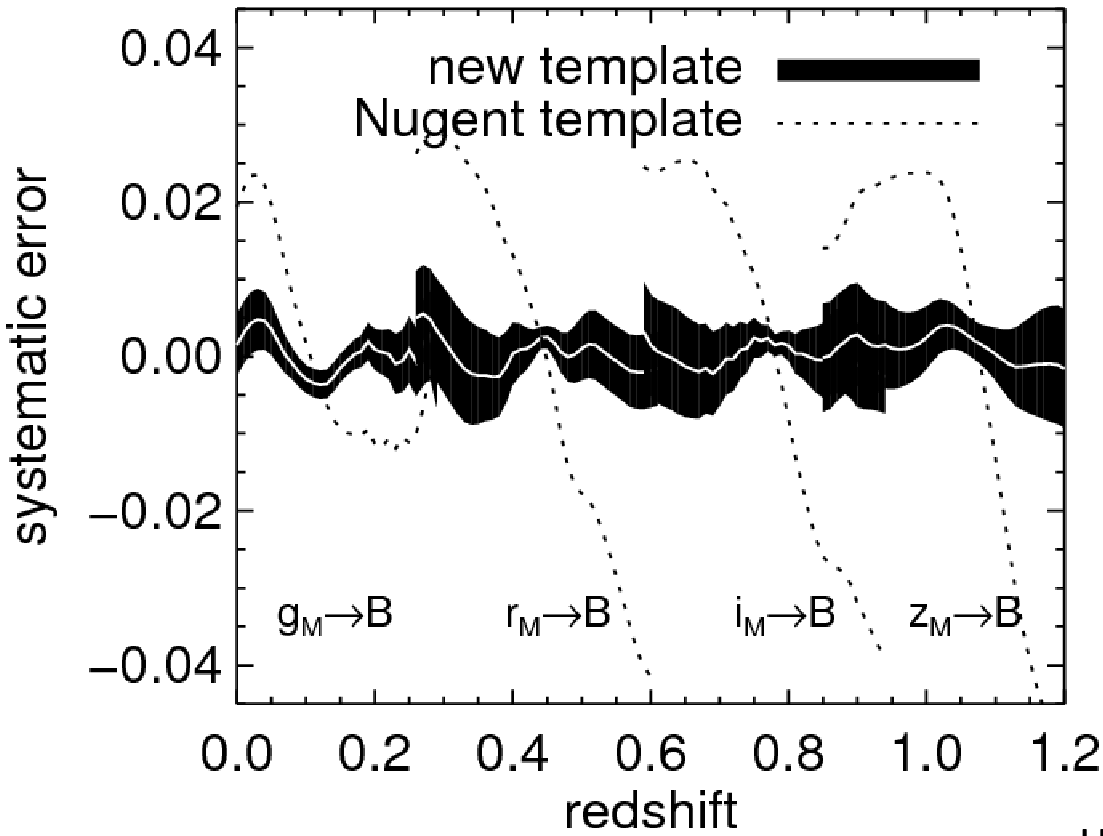


hsiao spectral template



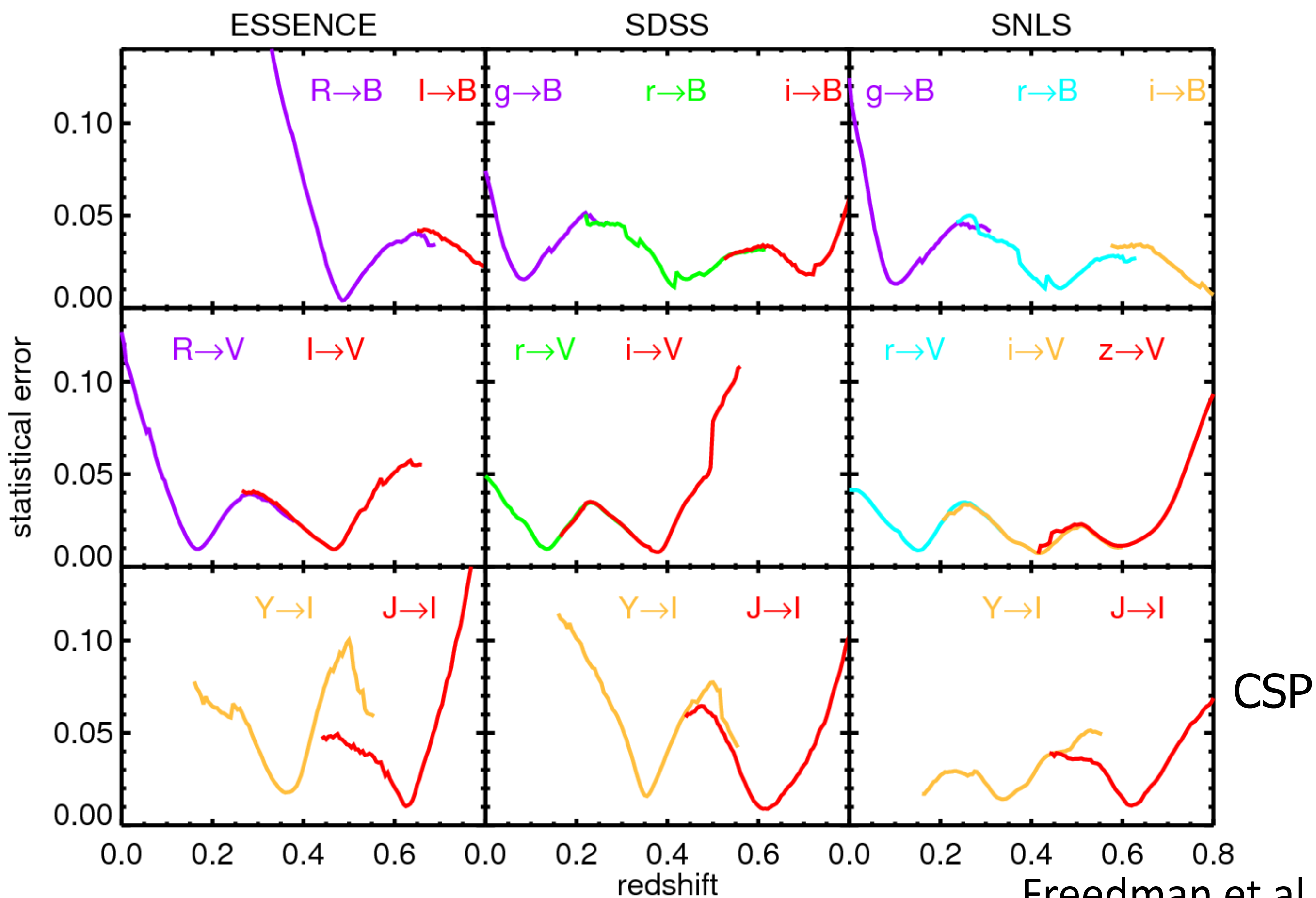
Nugent et al. (2002)
Hsiao et al. (2007)

K-correction errors
systematic errors



Hsiao et al. (2007)

K-correction errors
statistical errors

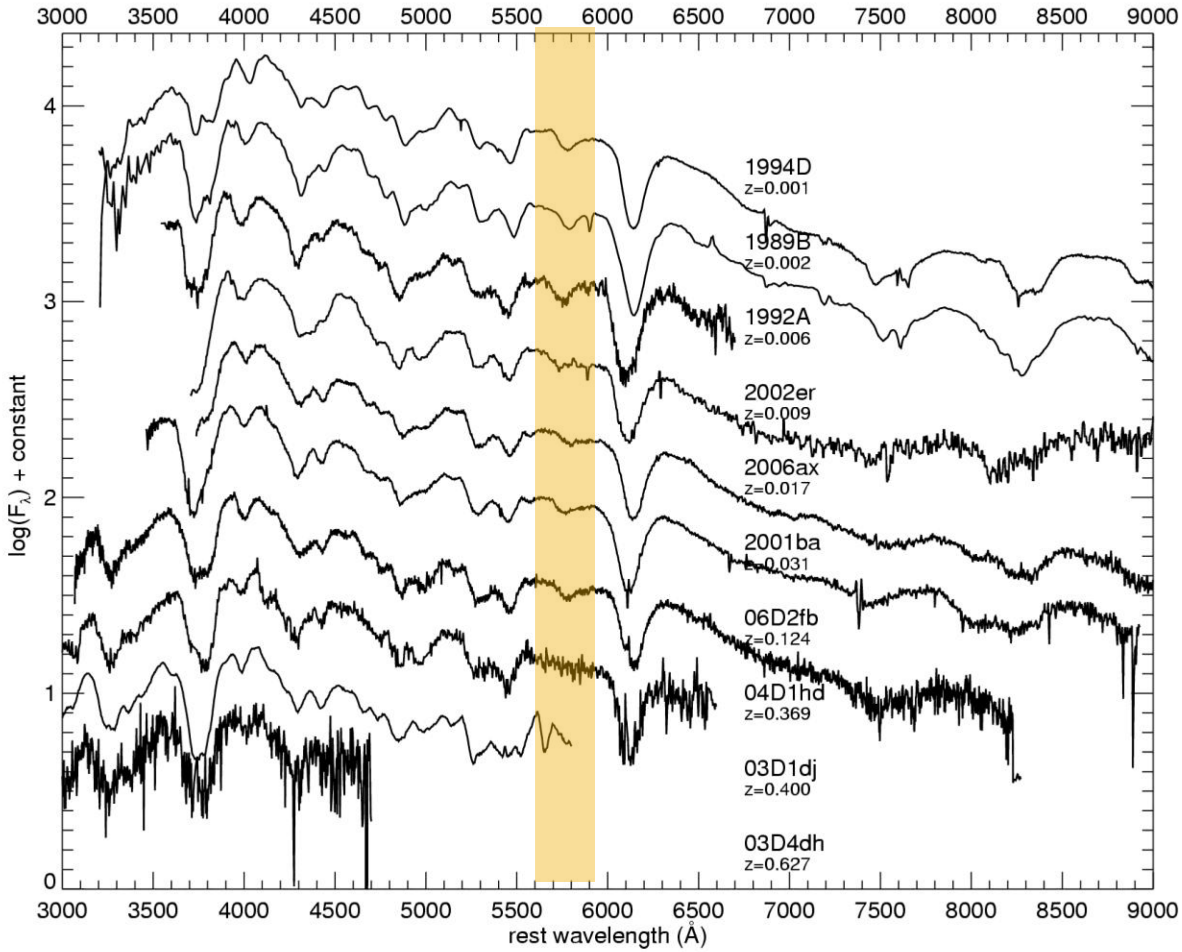


Freedman et al. (2009)

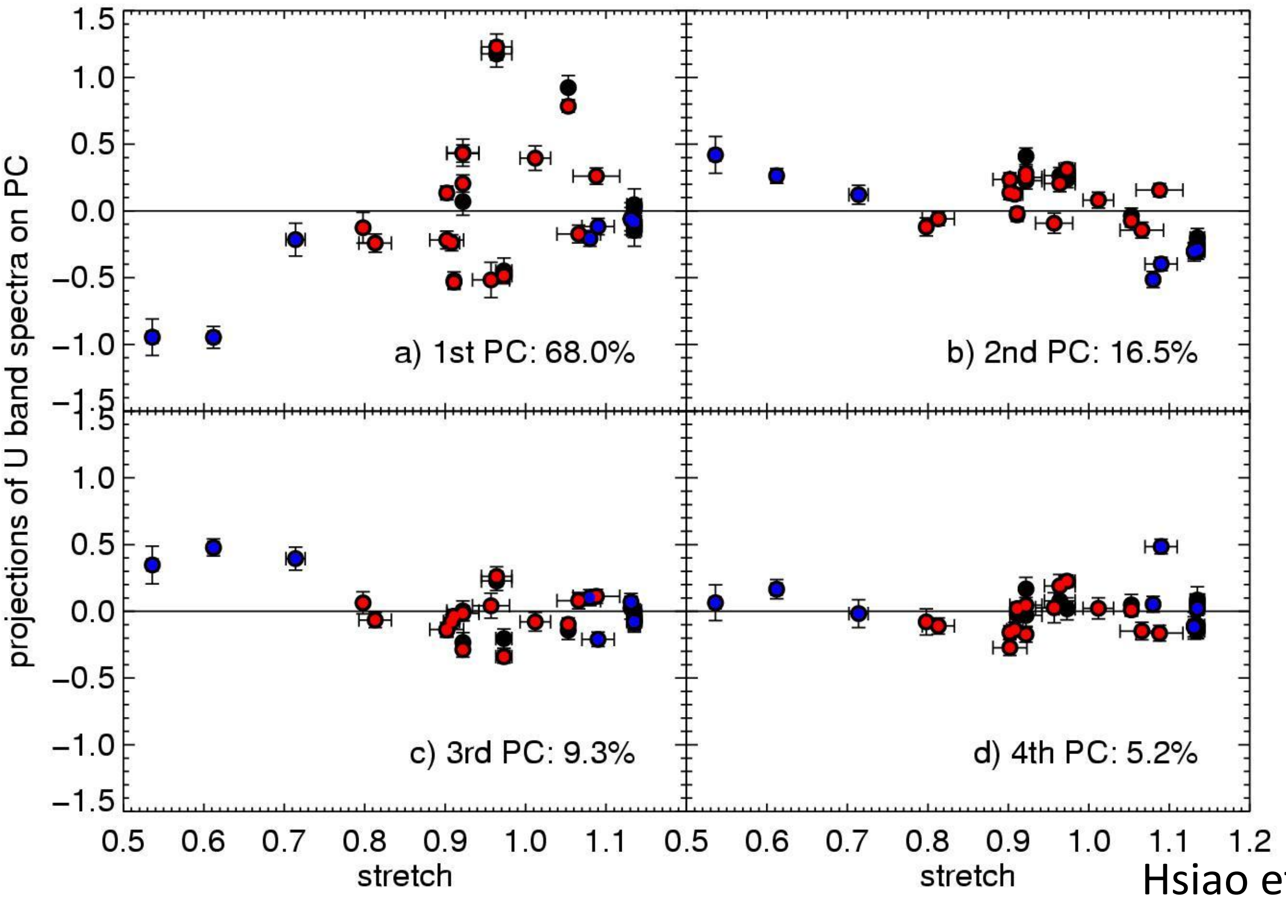
principal component analysis

- PCA reduces multi-dimensional data into PCs ξ_i
- 1st PC is the unit vector pointing toward the direction of the highest variance in the data space, and the rest are orthogonal vectors ranked by their variances
  $\left\langle \xi_i \middle| \xi_j \right\rangle = \delta_{ij}$
- projection of the *i*th spectrum on the *j*th PC is
  $p_{ij} = \left\langle f_i - \mu \middle| \xi_j \right\rangle$
- a set of spectra can be written as the sum of its PCs
  $\left| f_i \right\rangle = \left| \mu \right\rangle + \sum_{j=1}^{n} p_{ij} \left| \xi_j \right\rangle$

branch-normal SNe Ia

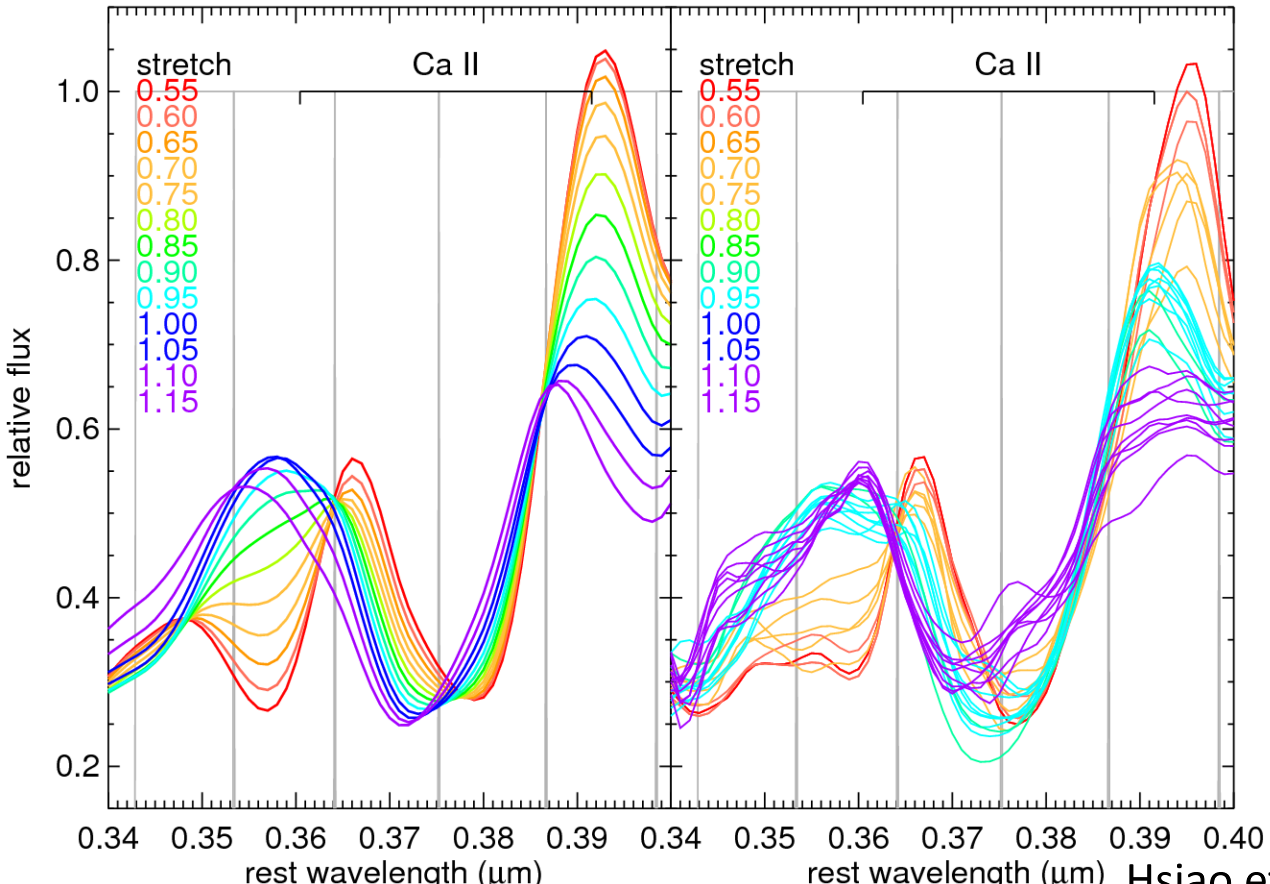


spectroscopic sequence
U band



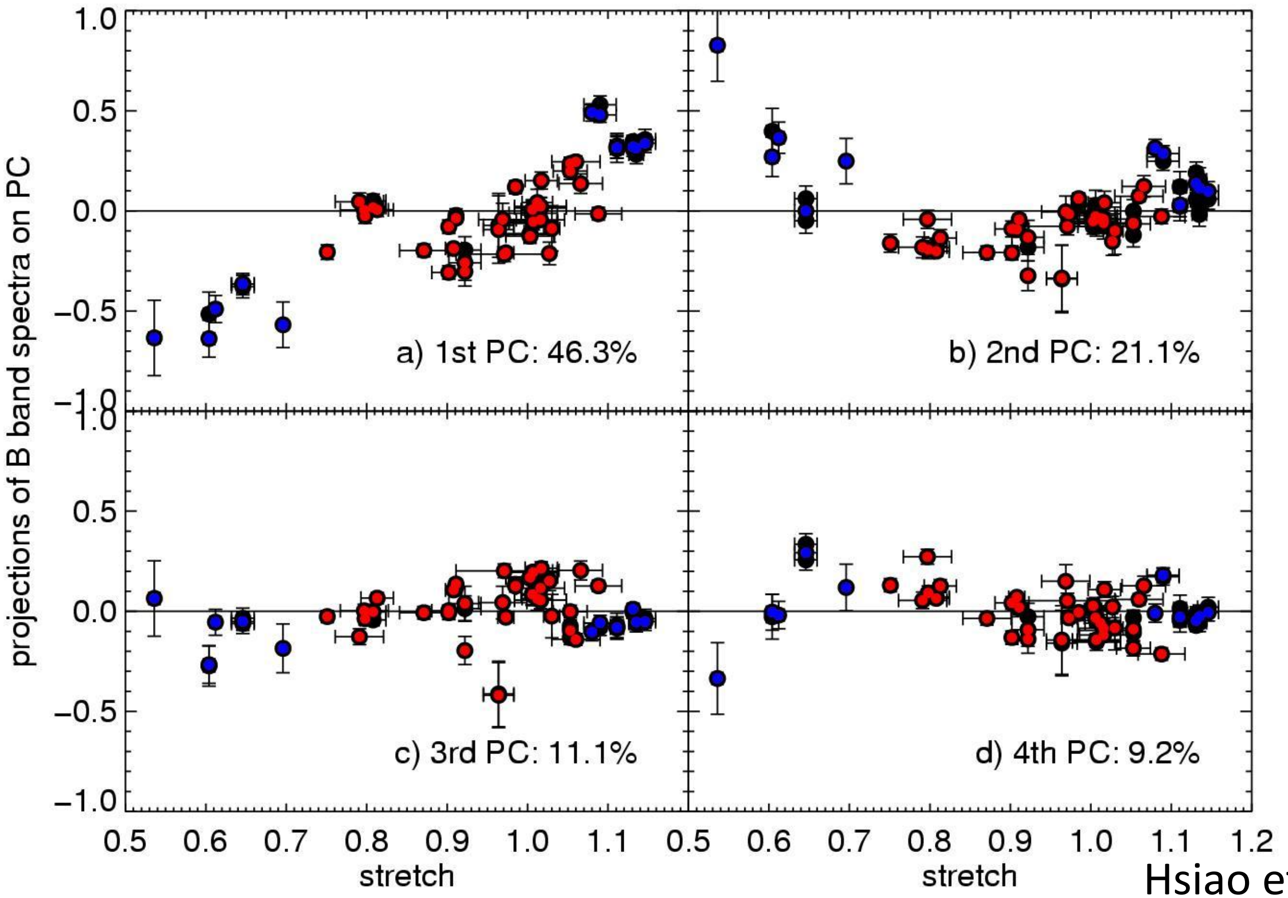
Hsiao et al. (2010)

spectroscopic sequence
U band



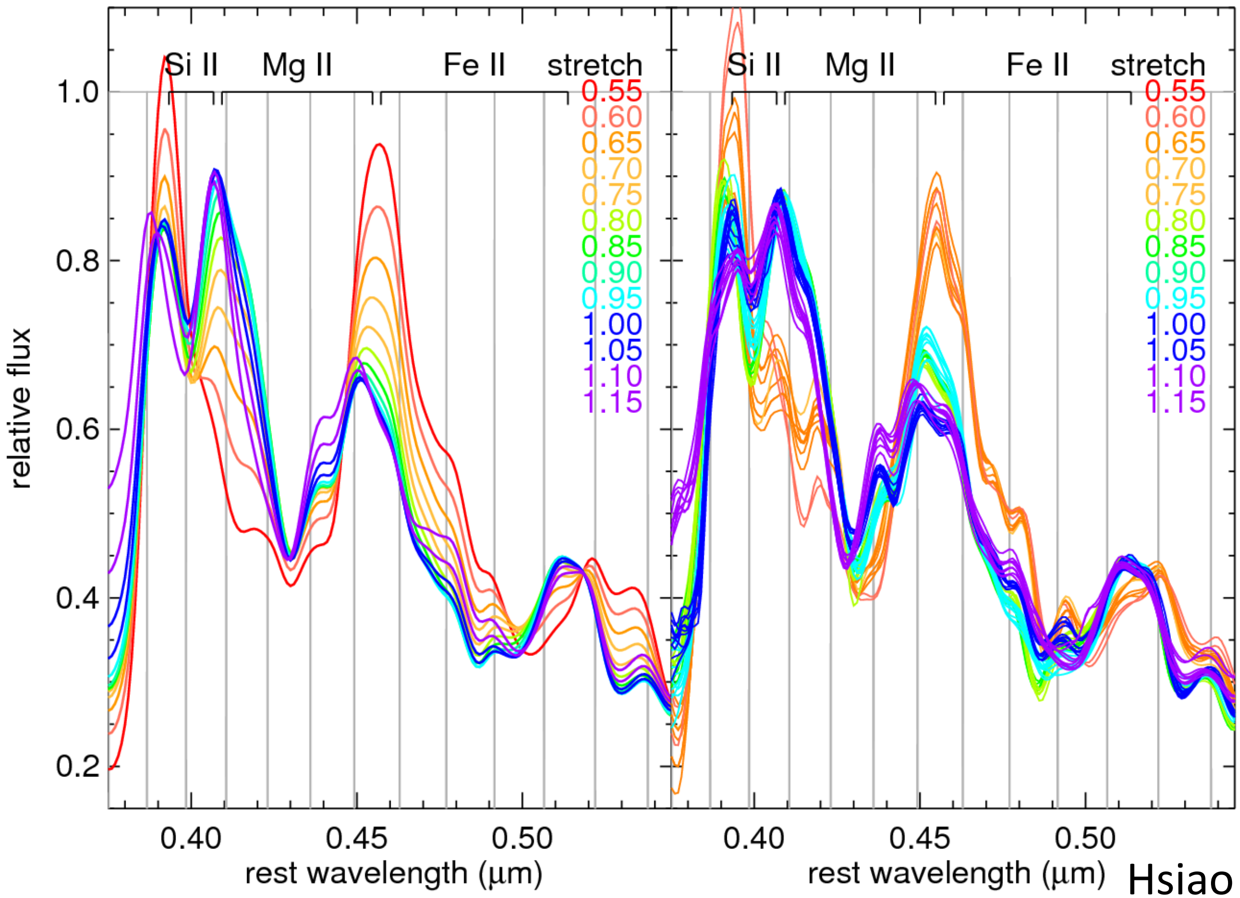
Hsiao et al. (2010)

spectroscopic sequence
B band



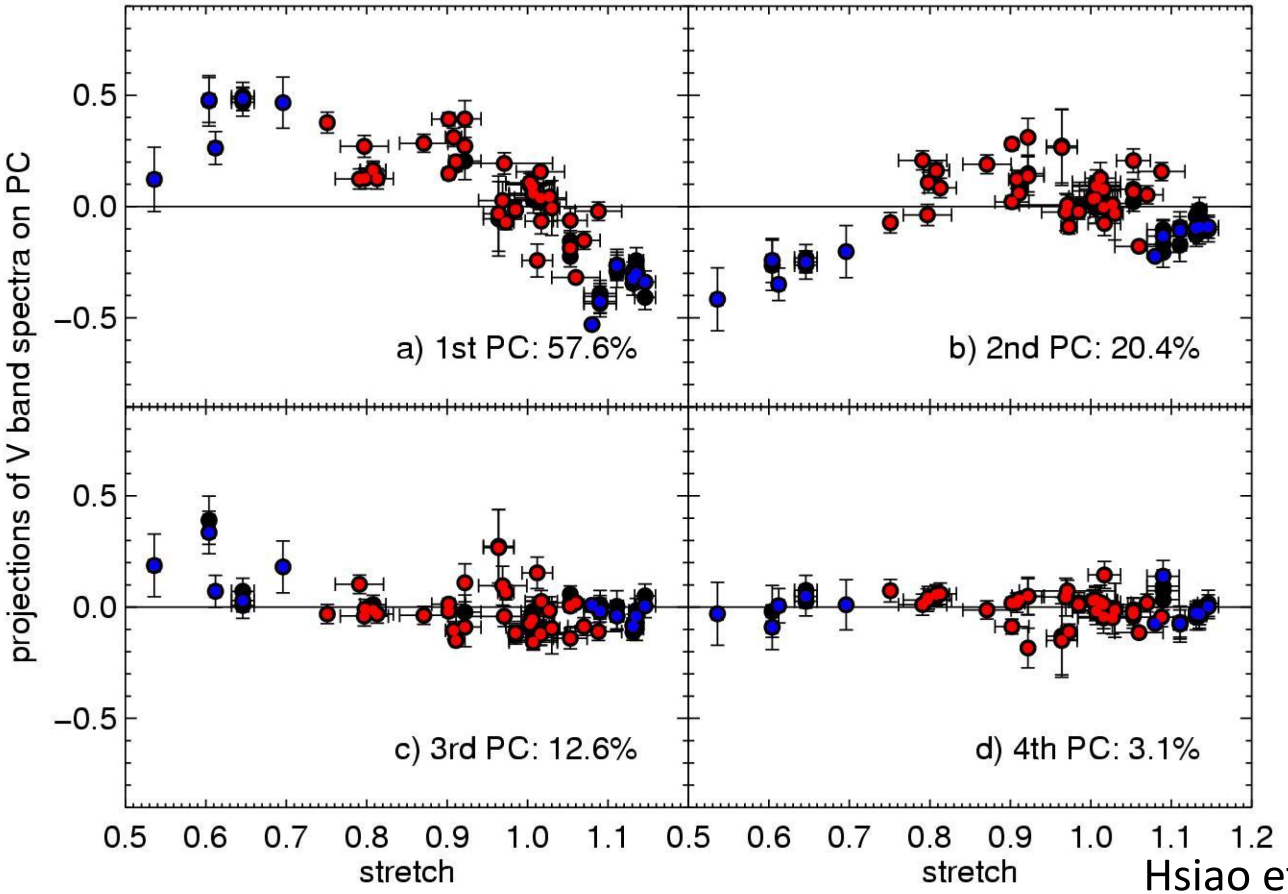
Hsiao et al. (2010)

spectroscopic sequence
B band



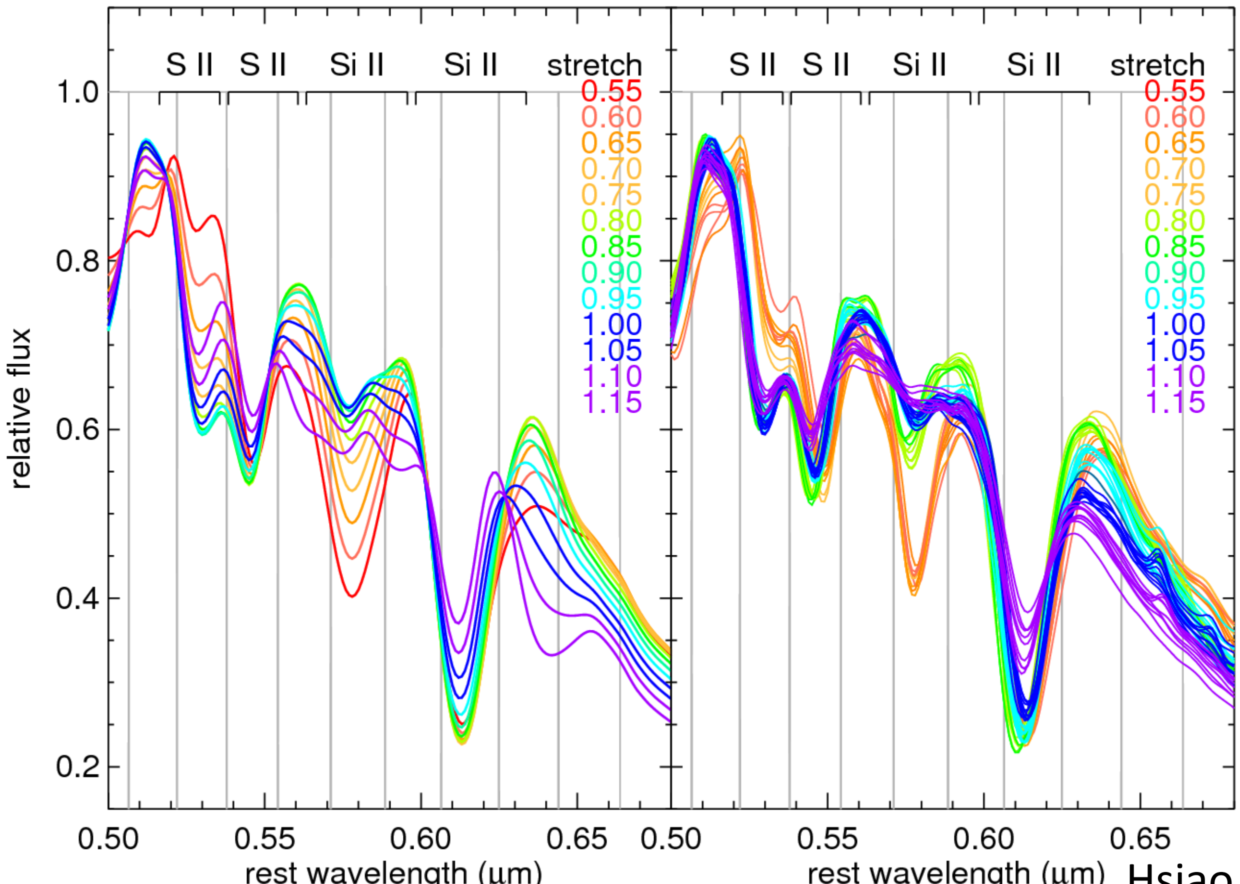
Hsiao et al. (2009)

spectroscopic sequence
V band



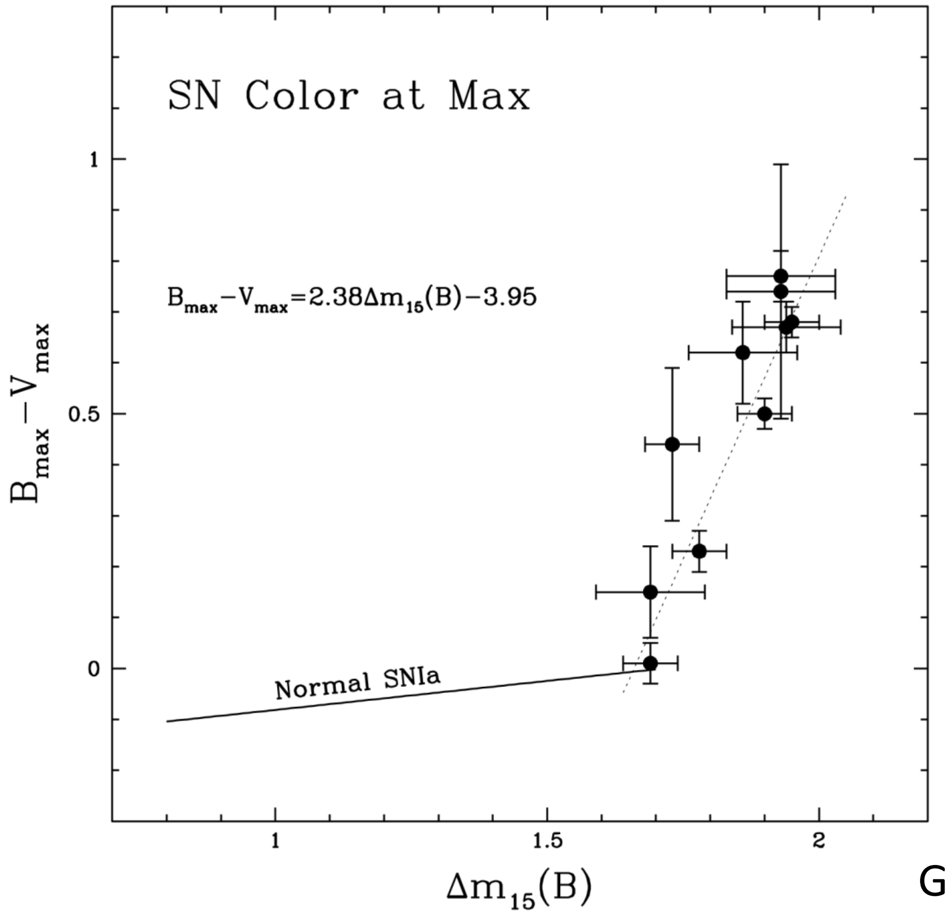
Hsiao et al. (2010)

spectroscopic sequence
V band



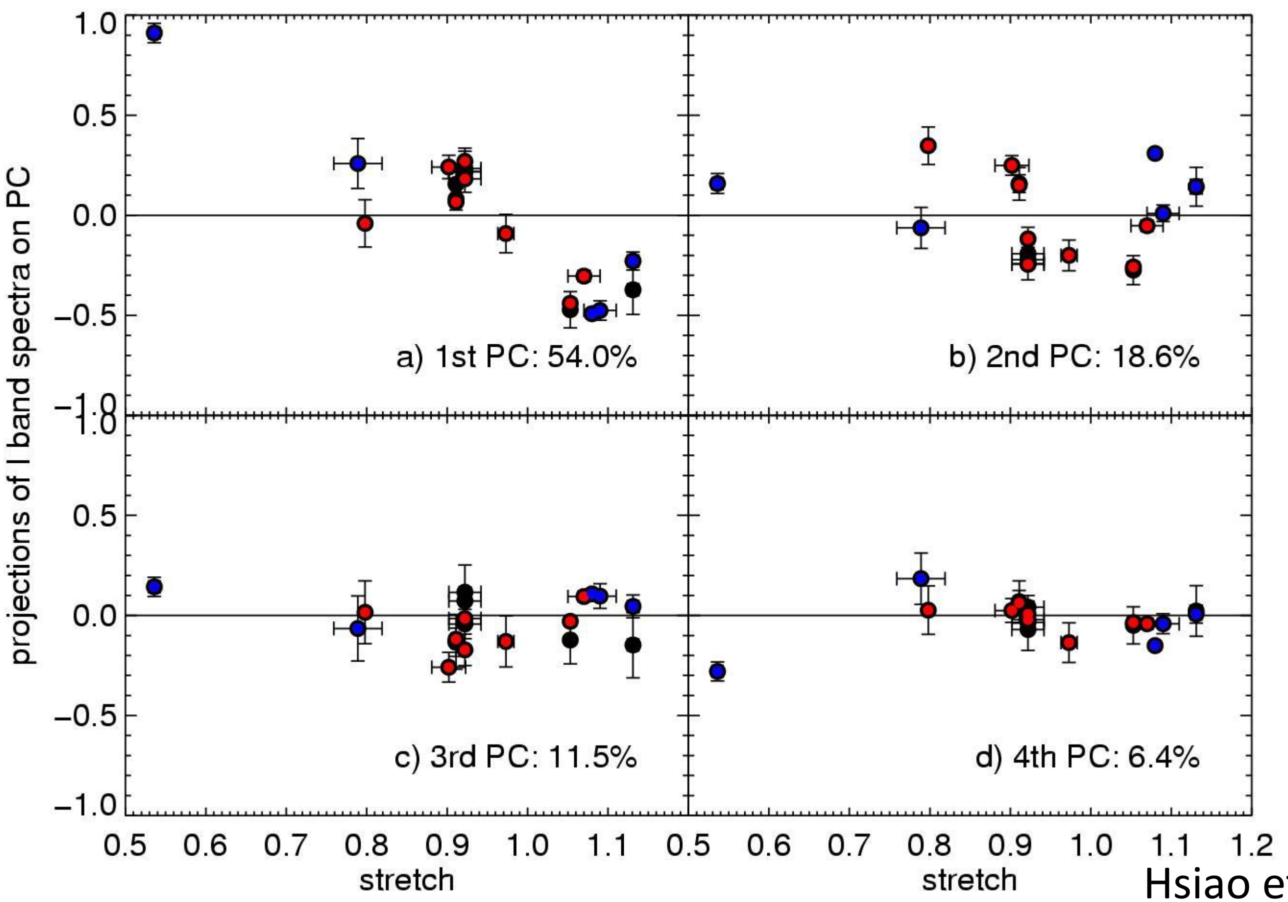
Hsiao et al. (2009)

peculiar vs normal



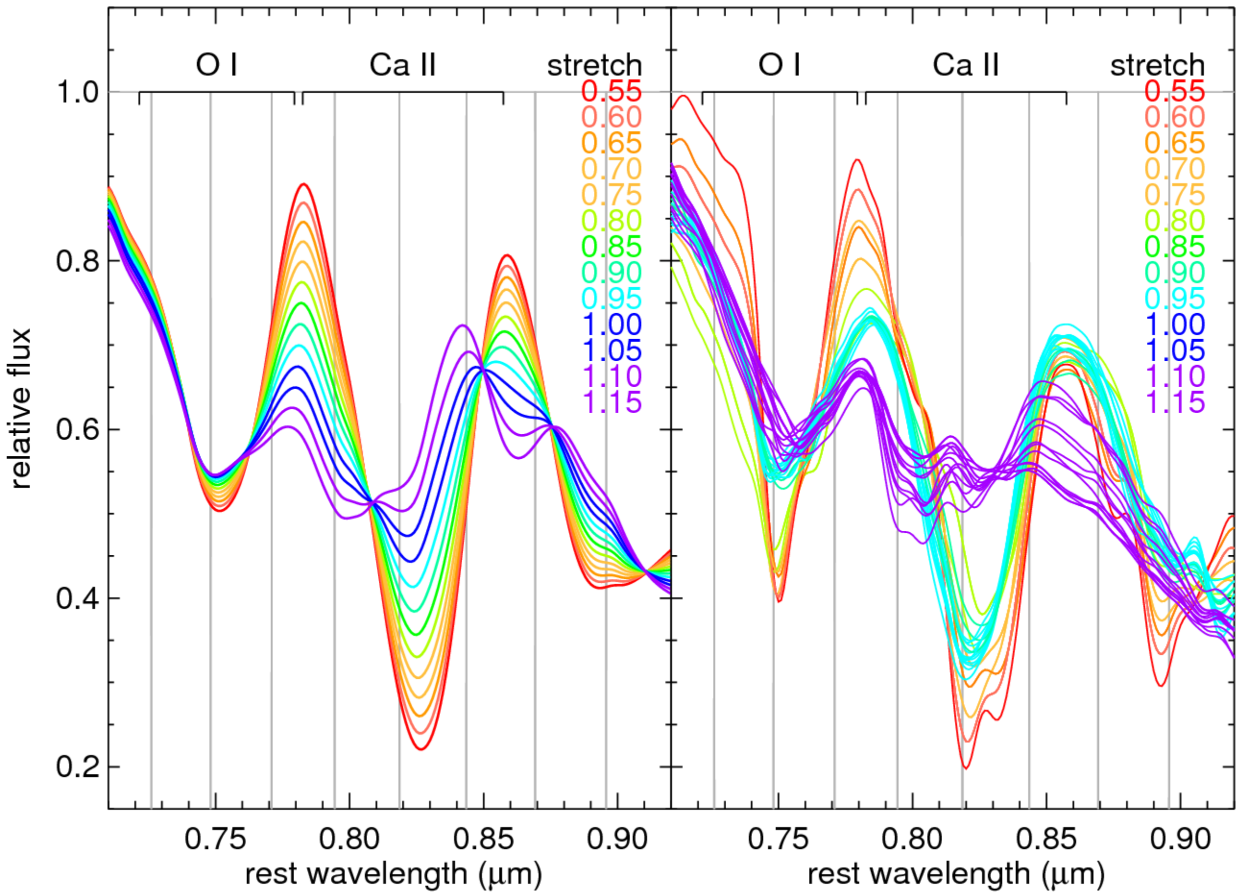
Garnavich et al. (2004)

spectroscopic sequence
I band



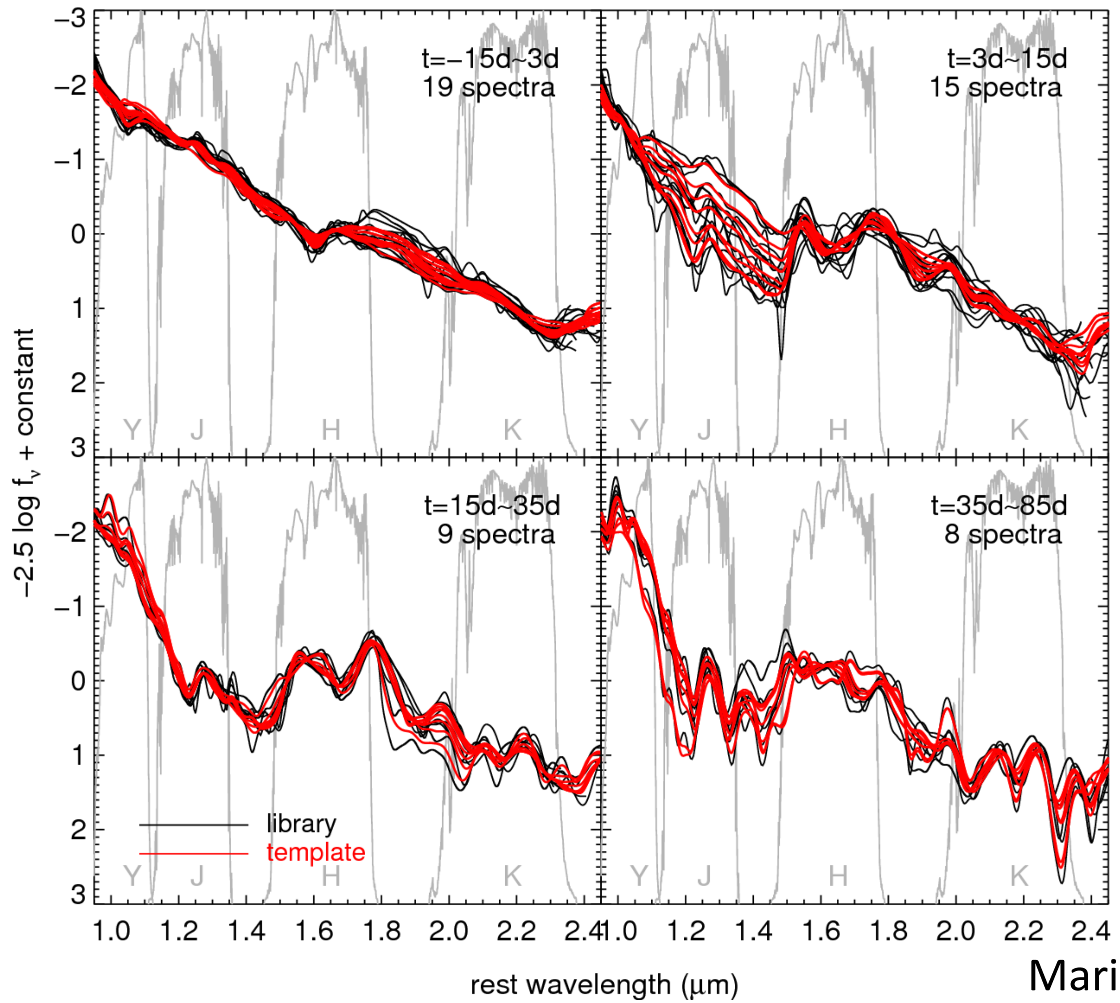
Hsiao et al. (2010)

spectroscopic sequence
I band



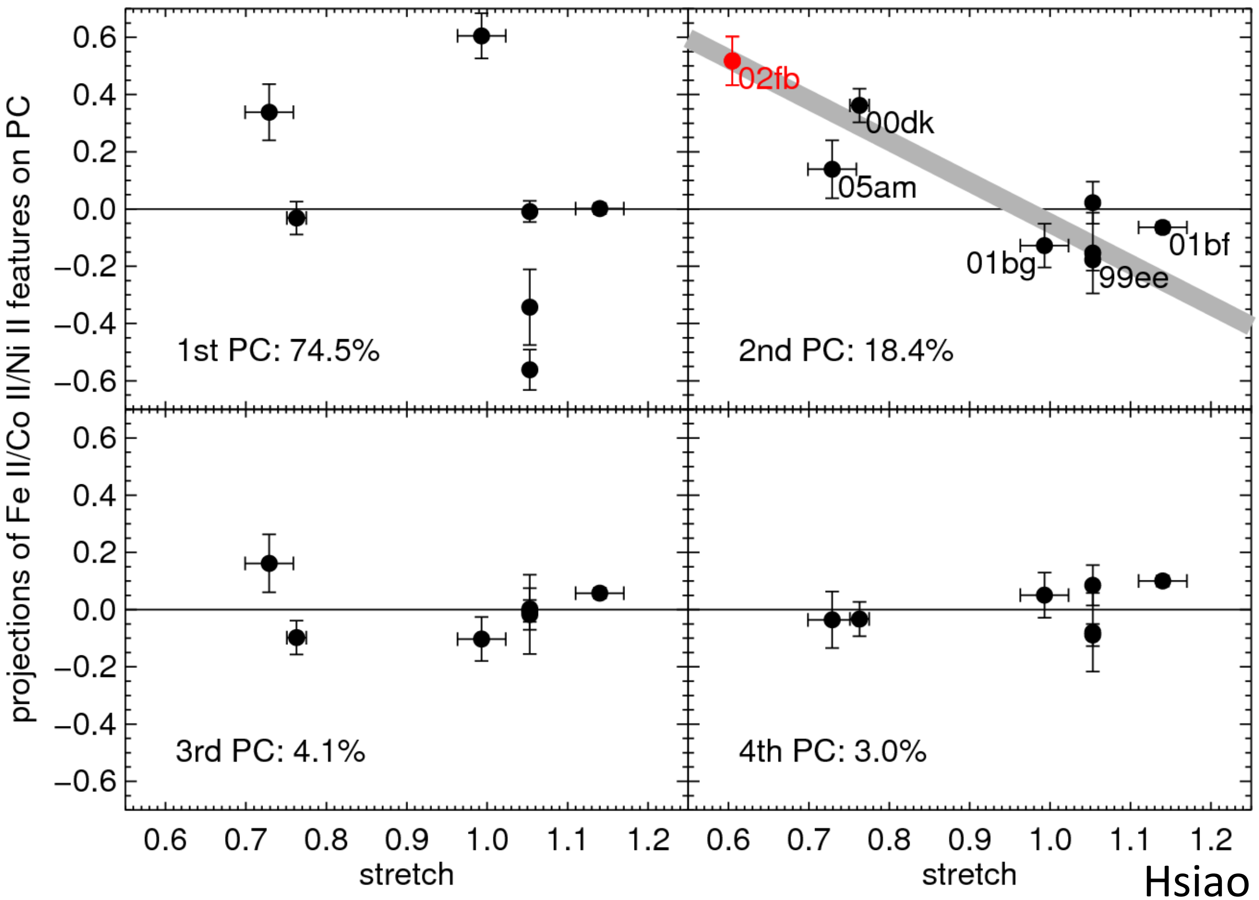
Hsiao et al. (2010)

spectroscopic sequence
near-infrared



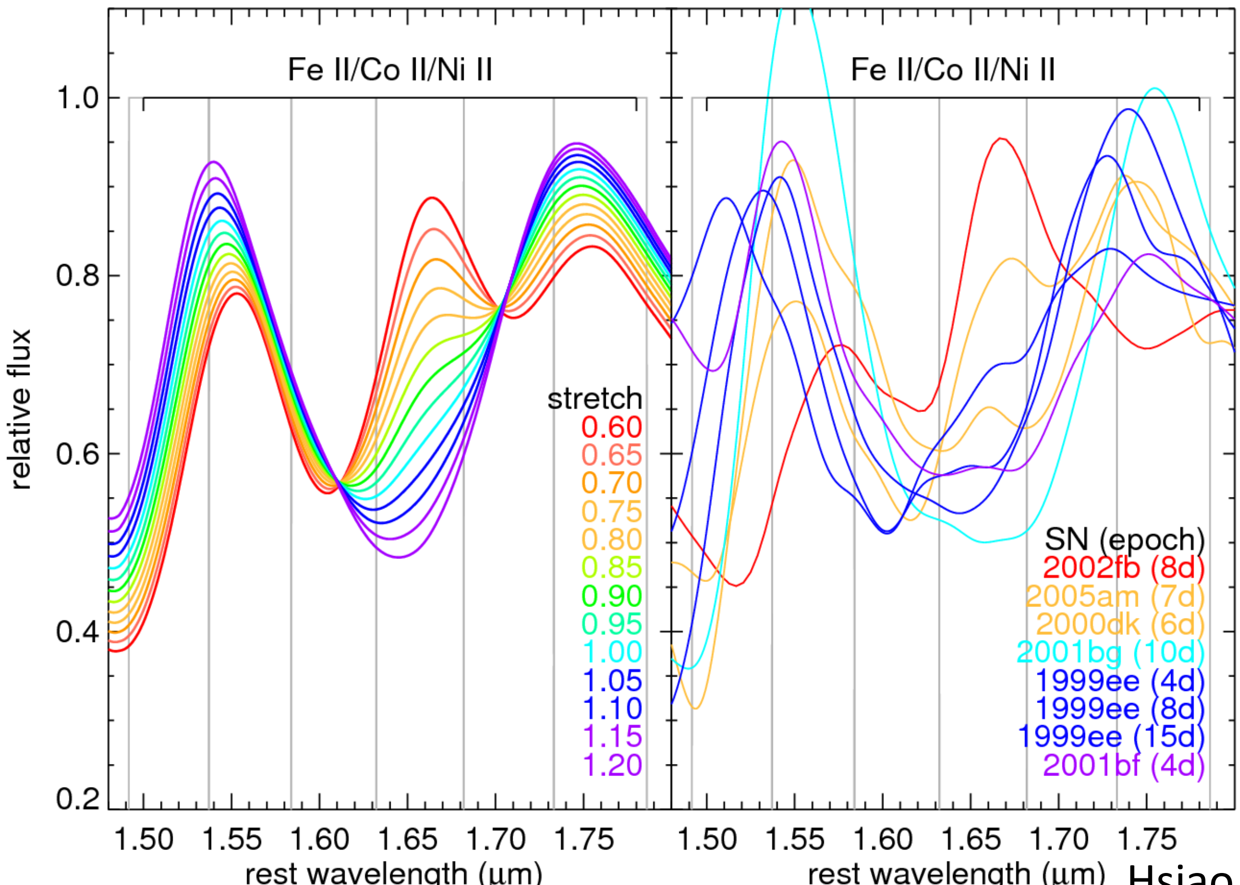
Marion et al. (2009)

spectroscopic sequence
H band



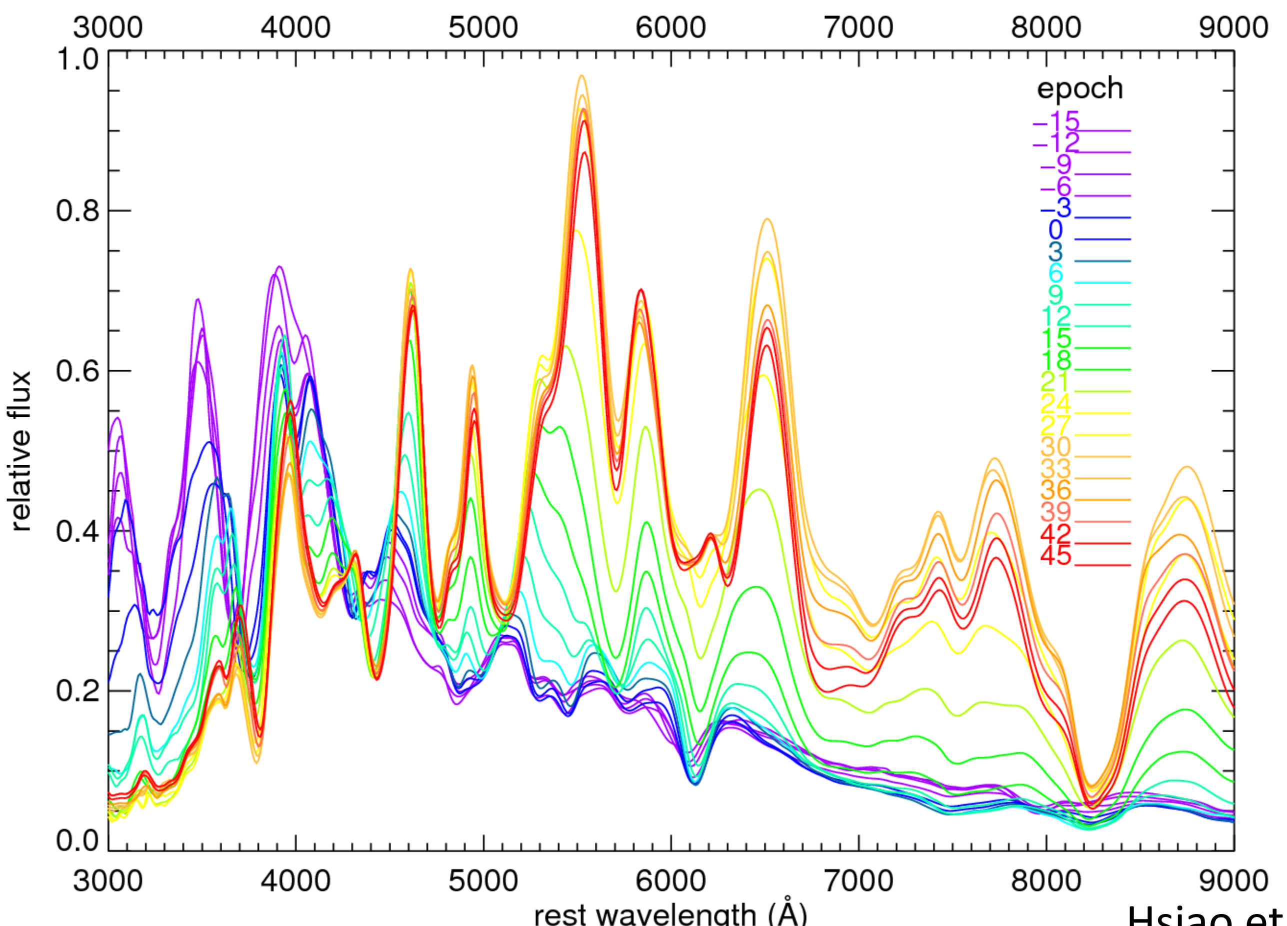
Hsiao et al. (2010)

spectroscopic sequence
H band



Hsiao et al. (2010)

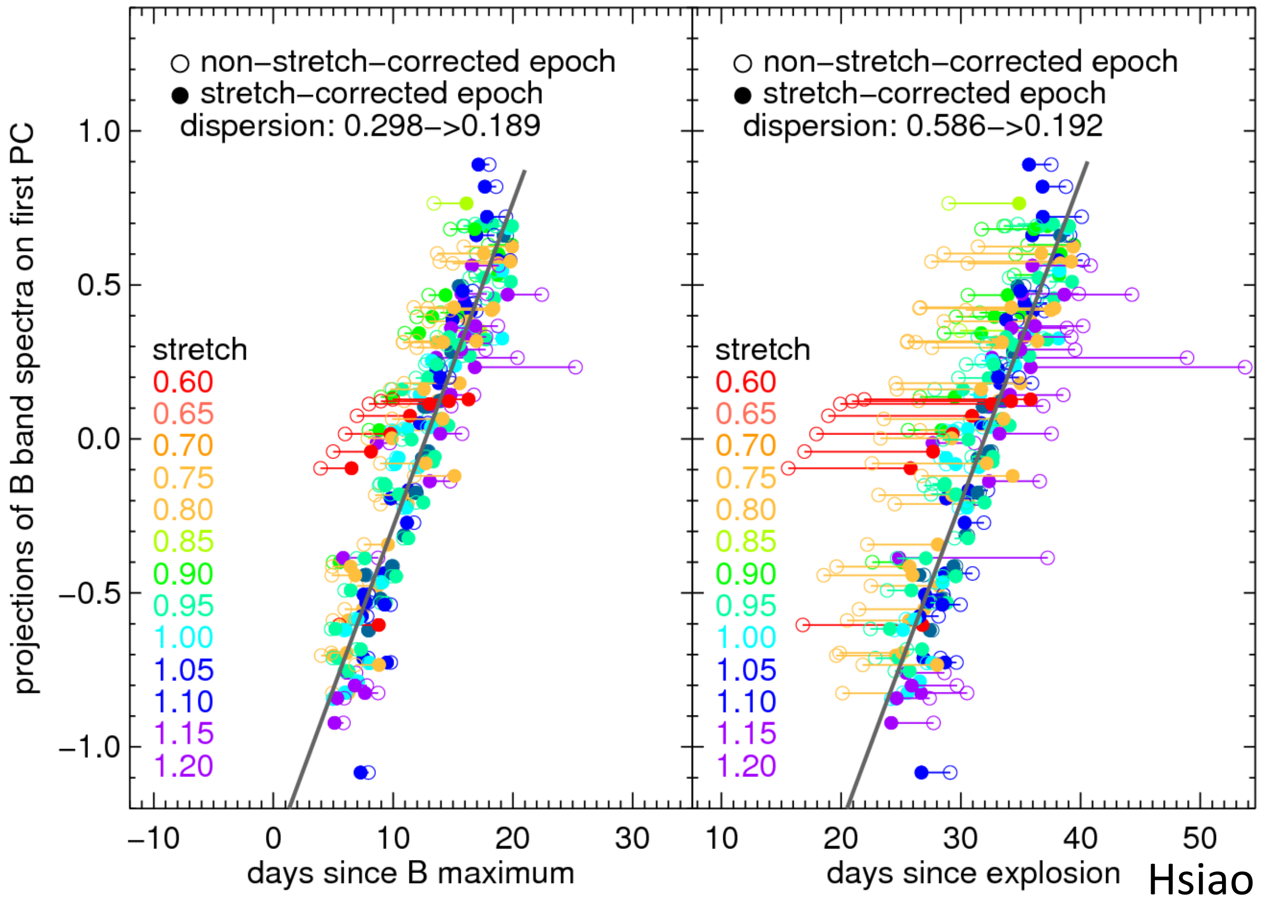
temporal evolution



Hsiao et al. (2007)

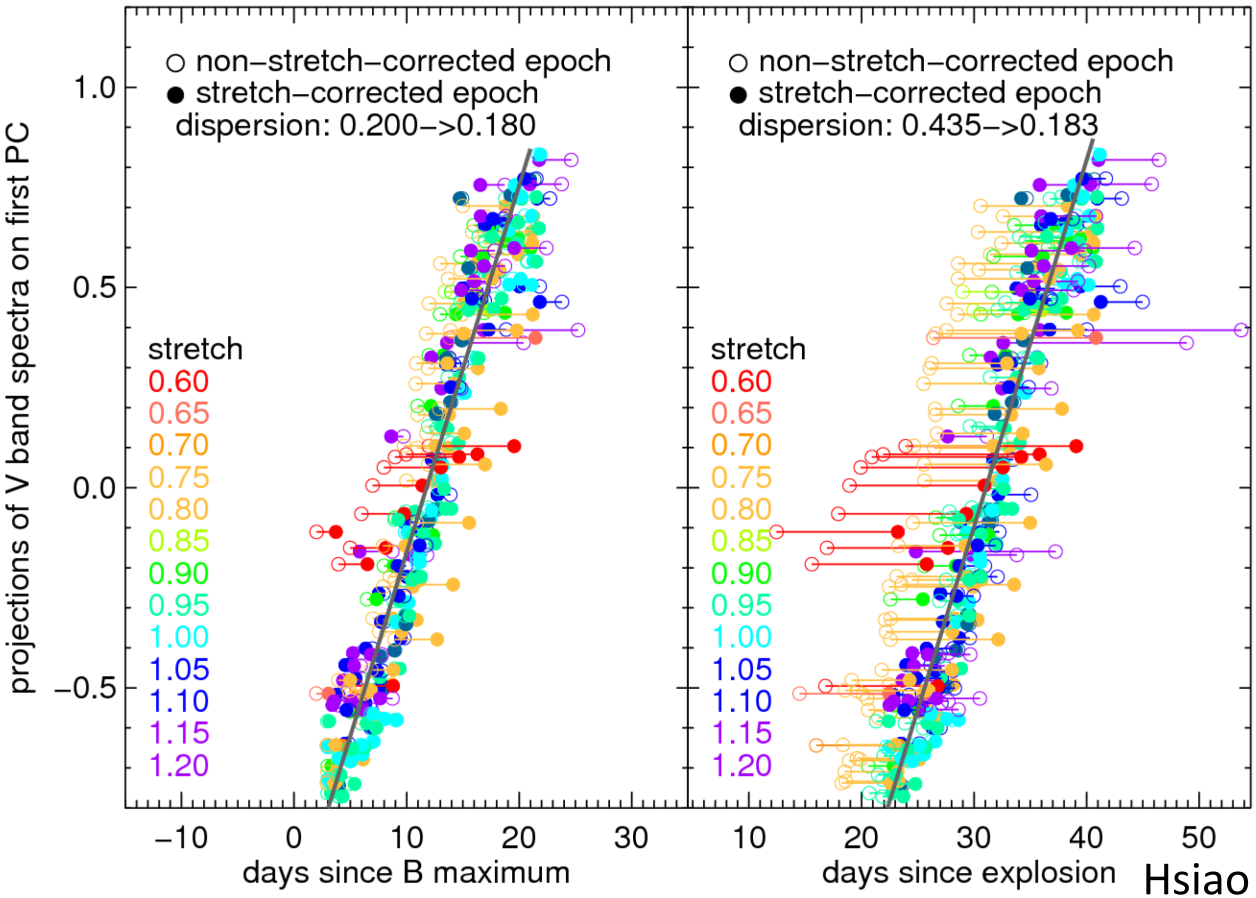
temporal evolution

B band



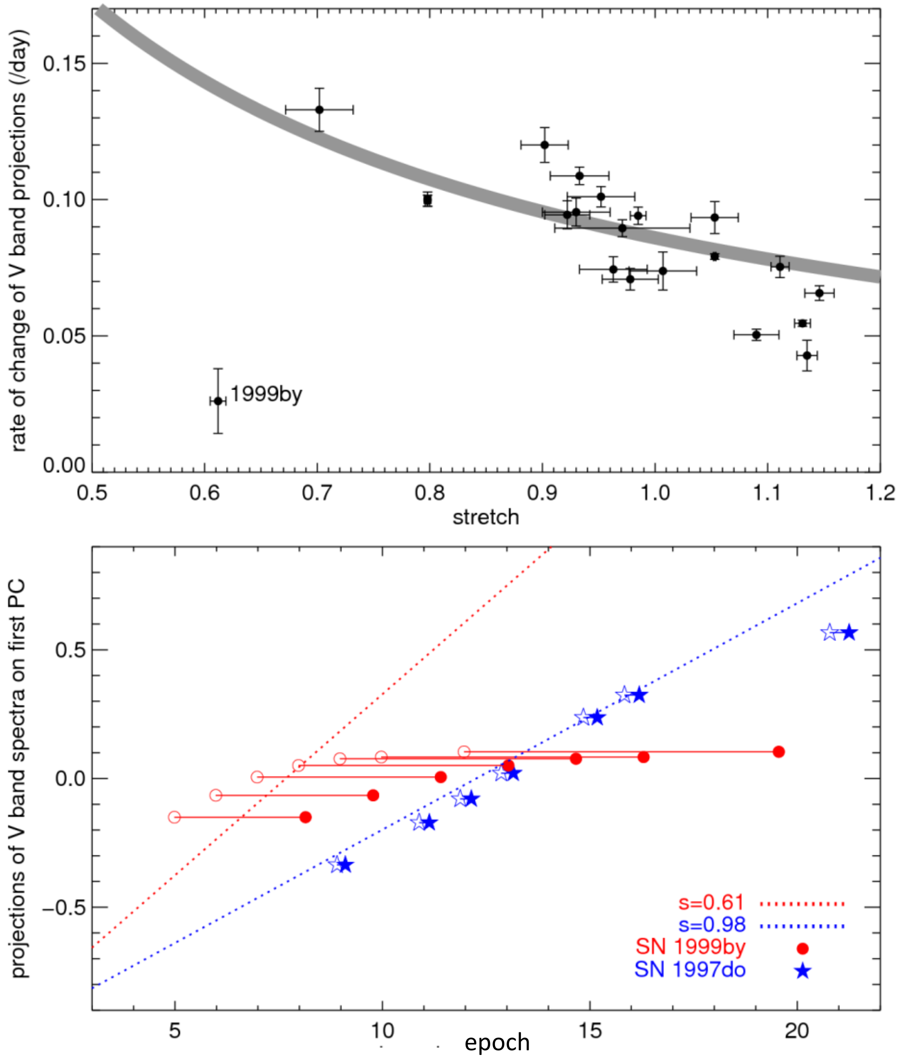
Hsiao et al. (2010)

temporal evolution
V band



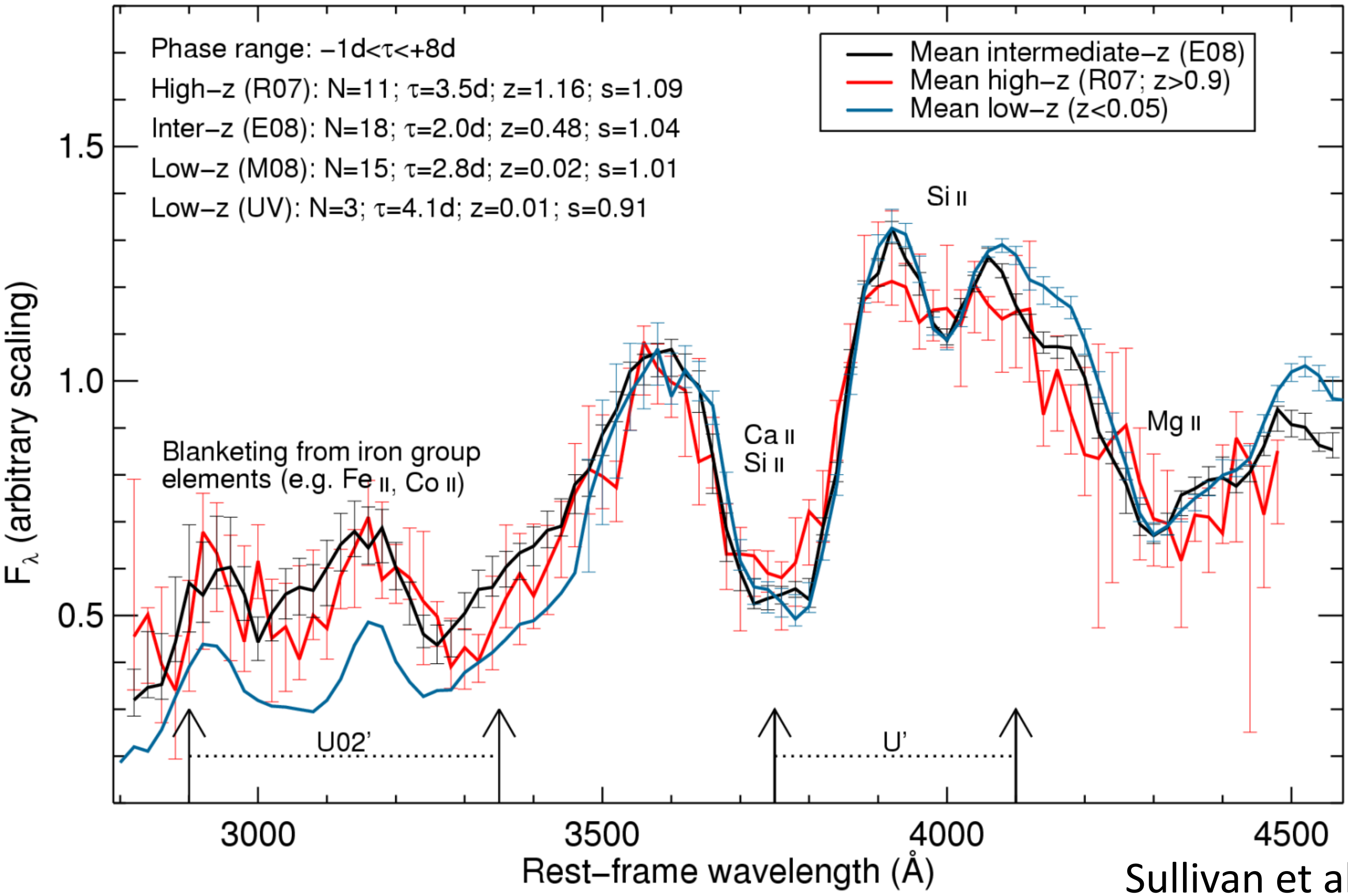
Hsiao et al. (2010)

temporal evolution
V band



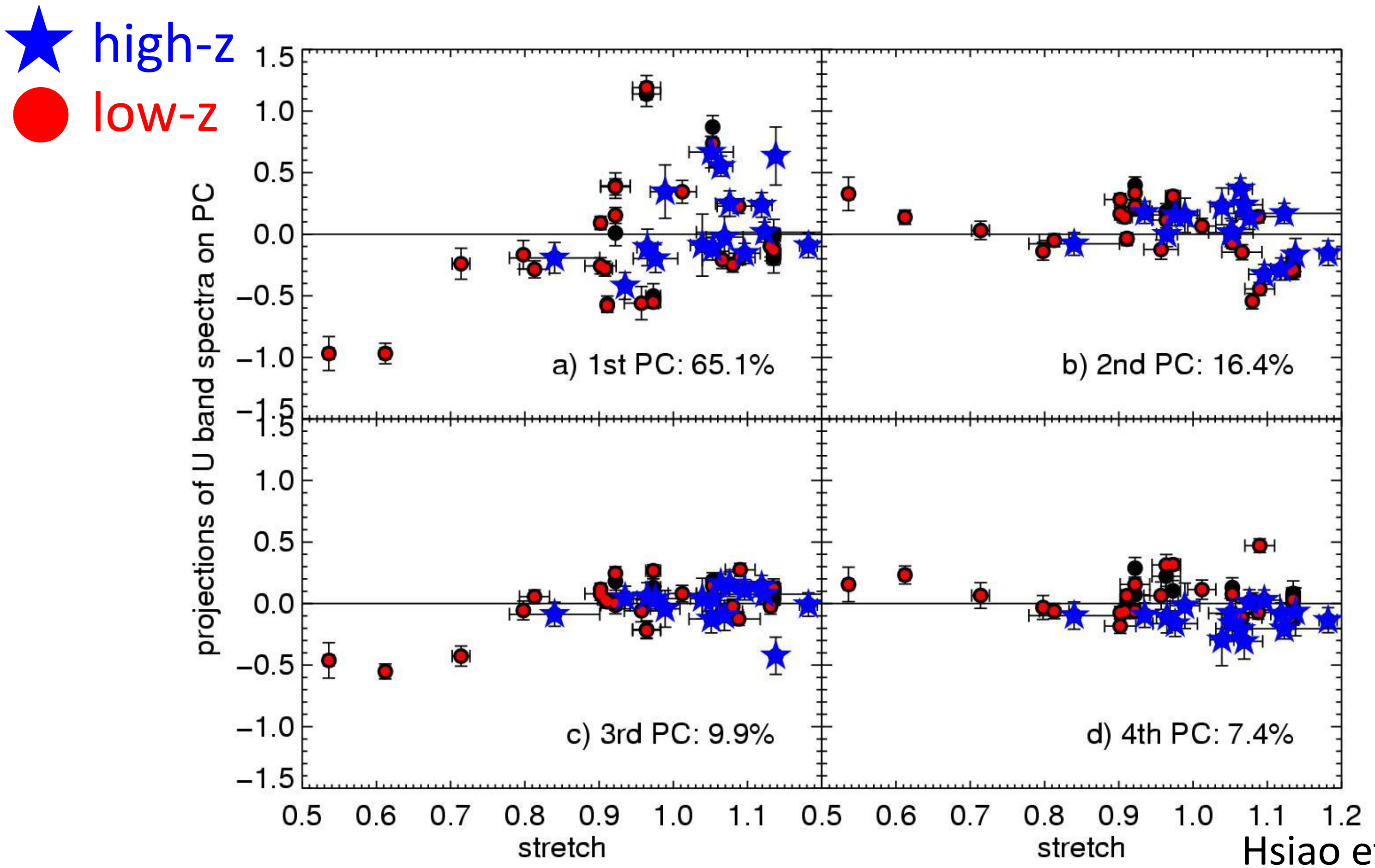
Hsiao et al. (2010)

redshift evolution?



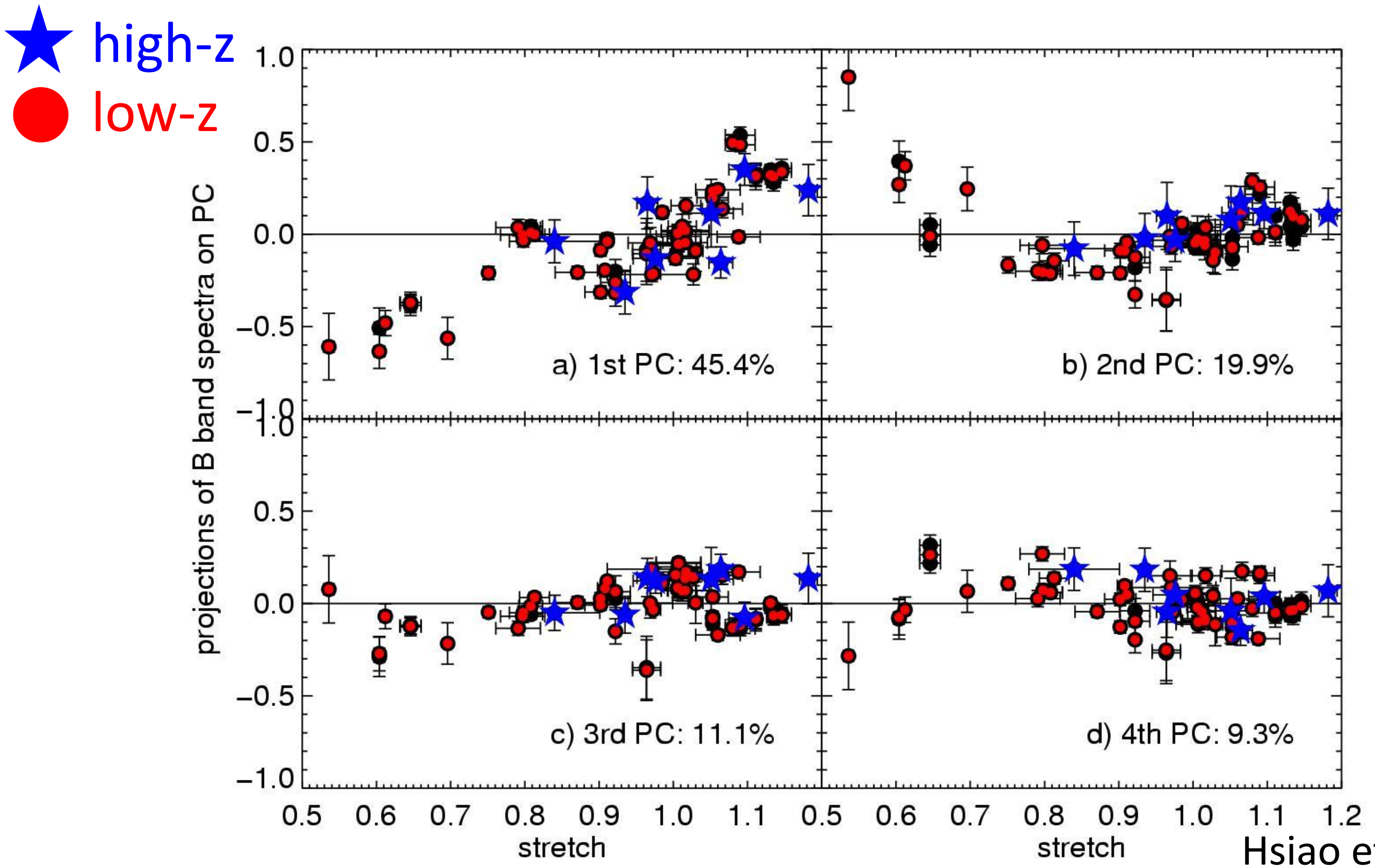
Sullivan et al. (2009)

redshift evolution?



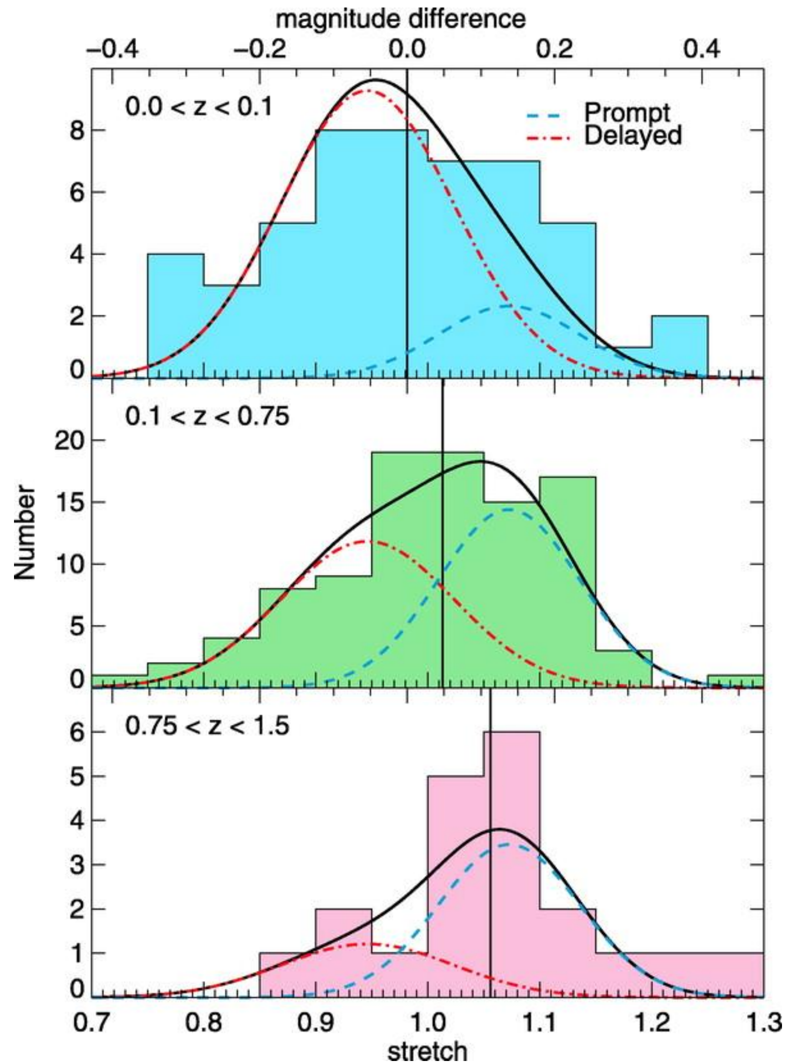
Hsiao et al. (2010)

redshift evolution?



Hsiao et al. (2010)

redshift evolution?



Howell et al. (2007)

impact on cosmology

sources of K-correction errors	Δmag
broadband color	10^{-1}
spectral features	10^{-2}
spectroscopic sequences	10^{-2}
evolution	small

conclusion

- light-curve width is a main driver of spectroscopic diversity
- evidence of discontinuity of spectral properties between normal and peculiar (1991bg-like) object
- time evolution of spectral feature also follow width-luminosity relation
- width-luminosity relation is a spectroscopic phenomenon, rather than bolometric
- differences in high- and low-redshift spectra can be explained by demographic shift